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TELEGRAPHY

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TELEGRAPHY

A DETAILED EXPOSITION OF THE TELEGRAPH SYSTEM OF THE BRITISH POST OFFICE

BY

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FOURTH EDITION
(WITH ADDENDUM)

WITH 640 ILLUSTRATIONS

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PREFACE
TO FOURTH EDITION

THE rapid exhaustion of the third edition has rendered it necessary to reprint the work, and this opportunity has therefore been taken to make a few additions to the text.

The chapter on Secondary Cells has been reviewed and some additional matter, suggested by Mr. R. G. de Wardt, has been incorporated. A description of the Kleinschmidt Perforator now forms part of Chapter X.

Appendix C on the Gulstad Relay has been re-written in view of the adoption of the G relay on so many long and difficult circuits. I am indebted to Mr. A. H. Roberts, M.B.E., for most of the information now given.

In the Addendum following the Appendix an elementary account of the amplifying valve has been provided, and my thanks are due to Messrs. C. Robinson and R. M. Chamney for checking this section. Whilst it is true that the device is not at present in use on telegraph circuits within the British Isles, there can be little doubt that its possibilities will not long remain unexploited.

The use of small currents to enable telegraph and telephone circuits to be worked in the same cable has far-reaching consequences. In this connection recent researches show that the old empirical rules for finding the working speed of circuits are fallacious. For aerial lines the determining factor is the value of the received current, and I am indebted to Mr. J. L. Taylor for an admirably concise account of his researches.

The vibroplex is described in the final section. Experiments are being made to ascertain whether its adoption lessens the strain on the telegraphist, reduces the liability to "cramp," and increases the output of work.

I wish to express my thanks to Major T. F. Purves, O.B.E., Lt.-Col. A. C. Booth, and Mr. Andrew Fraser for the assistance which they have so kindly afforded me.

During the preparation of the various editions of this work, I have received so much assistance from Mr. O. P. Moller that I desire to take this opportunity to place on record my appreciation of the help which he has so freely and so willingly rendered me.

T. E. H.

LONDON,
September, 1920.

EXTRACT FROM PREFACE TO FIRST EDITION

> The interdependence of theory and practice cannot be ignored without inflicting injury on both; and he is but a poor friend to either who undervalues their mutual co-operation.
>
> *Rt. Hon. A. J. Balfour at the British Association.*

THE objects of the present volume are to supply the admitted need for an up-to-date and detailed exposition of the telegraph practice of the British Post Office and also to provide for the requirements of the Departmental and City and Guilds' examinations in the subject. With the latter object in view I have furnished a plenitude of fully worked numerical examples and have included elementary accounts of galvanometers, battery testing, and the Wheatstone bridge. After anxious and careful consideration in the light of an extensive teaching experience I have deemed it best to avoid the use of mathematics, and I am satisfied that the more elementary method adopted will make the work accessible to the far larger and wider circle of readers who most need the information I have sought to convey.

The Journal of the Proceedings of the Institution of Electrical Engineers, the *Electrical Review* and the *Electrician* have naturally been freely consulted during the preparation of the work.

I beg to acknowledge my indebtedness to:—Sir Samuel Boulton, Messrs. J. E. Kingsbury, E. J. Chambers, A. H. Atkins, D. Murray, W. S. Steljes, and F. Crawter; also to the following gentlemen of the Post Office Department:—Messrs. M. F. Roberts, J. W. Willmot, H. R. Kempe, H. Hartnell, T. F. Purves, J. R. M. Elliott, C. C. Vyle, G. F. Mansbridge, W. Moon, H. Wilson, H. A. Miles, W. J. Stubbs, W. E. Twells, R. Ianson, E. I. T. Newton, and A. Q. Ellery.

The list which follows comprises those firms to whom I desire to acknowledge my obligations either for illustrations taken from their catalogues or for special information relating to the materials which they manufacture or supply:—

Messrs. The British Insulated Wire Co.; British L. M. Ericsson Manufacturing Co.; Buck and Hickman; Bullers; Burt, Boulton, and Haywood; Chloride Electrical Storage Co.; W. F. Dennis; Electrical Power Storage Co.; Elliott Bros.; General Electric Co.; Hart Accumulator Co.; India-rubber, Gutta-percha, and Telegraph Works Co.; London Electric Wire Co.; Muirhead and Co.; Nalder Bros. and Co.; Siemens Bros. and Co.; Sterling Telephone and Electric Co.; Typewriting Telegraph Corporation; Western Electric Co.

The material assistance which I have received has been so freely and so willingly given that it seems almost invidious to make distinctions, but owing to the larger demands I have made upon Mr. Hartnell, I feel that it is impossible to allow this opportunity to pass without a definite expression of my warm appreciation of the numerous and valuable suggestions which he has made whilst reading the proof sheets. To Mr. Ianson, also, I desire to express my cordial thanks for the services which he has rendered to me in reading and criticizing both the original manuscript and the proof sheets.

With the exception of the manufacturers' blocks, the drawings for the illustration of the text have been prepared by Mr. O. P. Moller, to whom my thanks are conveyed for the care and thought which he has bestowed upon the work.

EXTRACT FROM
PREFACE TO THIRD EDITION

CHANGES and improvements in detail have likewise been prolific, with the result that a large proportion of this work has necessarily been rewritten or rearranged. This task has been vastly facilitated by the advent of the Institution of Post Office Electrical Engineers and the *Post Office Electrical Engineers' Journal*. The Proceedings of this Institution and its *Journal* have been very freely used, and I am much indebted to the Council of the Institution and to the Board of Editors for the readily accorded permission to utilize these records. To the Proceedings of the Institution of Electrical Engineers I am likewise under obligation, which I desire here to place on record.

To the Electrical Press I am also under obligation, and my thanks are expressed to *Electrical Engineering*, the *Electrical Review*, the *Electrician*, and to *Electricity*.

I beg to acknowledge my indebtedness to: Messrs. Martin F. Roberts, H. Hartnell, Donald Murray, H. H. Harrison, F. Crawter, F. G. Creed, J. Gell; also to the following gentlemen of the Post Office Engineering Department: Messrs. T. F. Purves, D. H. Kennedy, E. Lack, T. Lakey, S. C. Bartholomew, W. C. Cruickshank, W. A. Hatfield, E. A. Lakey, J. G. Lucas, O. P. Moller, E. I. T. Newton, E. V. Smart, A. E. White, T. Smerdon, and P. D. Moller.

The list which follows comprises those firms to whom I am indebted for illustrations taken from their catalogues or for special information relating to materials which they manufacture or supply—

Messrs. The Automatic Telephone Co.; British Insulated and Helsby Cables; Elliott Bros.; Evershed and Vignoles; Nalder Bros.; New Phonopore Telephone Co.; R. W. Paul; Peel Connor Telephone Co.; Siemens Bros.; and The Western Electric Co.

T. E. H.

LONDON, *August*, 1916.

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TELEGRAPHY

INTRODUCTION

THE FUNDAMENTAL PRINCIPLES OF MAGNETISM AND ELECTRICITY, AND UNITS.

STATIC ELECTRICITY.

ELECTRICITY pervades all matter, but it is only when its distribution is altered that its presence is observed by the effects which result. One method of accomplishing this is by rubbing substances together, but the effect is due more to intimacy of contact between every portion of each surface than to actual friction. The result is that the two substances pass from the normal to the electrified condition. The condition of the two substances is different, and one is said to be positively and the other negatively electrified. The terms positive and negative are respectively used to imply a surplus above and a deficiency below the normal amount of electricity present.*

If a dry glass rod is rubbed with silk, it will be found that the glass is positively and the silk negatively electrified. A list may be prepared (from the results of experiments) in which substances are placed in such an order that upon any two substances named being rubbed together the resulting electrical condition of each may be stated according to their relative positions upon the list.

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* Recent research shows that the negatively electrified body has the excess of electricity, and that, therefore, the true direction of a current is opposite to that in which it is at present assumed to pass.

The electrified condition of a body may be imparted to others either by direct contact or by induction. Experiment proves that bodies similarly electrified, or charged, repel, and bodies oppositely charged attract each other.

It is vitally important to notice that in every case in which electrification results the values or quantities of positive and negative electrification are equal. This fact may be proved experimentally, or it may be deduced by mathematical analysis. If, therefore, a positive and a negative charge have been produced—suitable conditions being provided—an electric current will flow from the positively to the negatively electrified body until electrical equilibrium has been restored. Where these conditions have not been provided there always exists a force of attraction between the bodies.

POTENTIAL.

The term potential implies the power or capacity to do work.* Now a charged body is endowed with the power of attracting light substances—a property which an uncharged body does not possess. The uncharged body is said to be at zero potential, whilst the charged body has a positive or negative value according to the sign of its electrification. Potential corresponds very closely to level as applied to water, and just as a flow of water takes place from a higher to a lower level, so does a flow of electricity or an electric current take place from a higher to a lower potential in its endeavour to restore electrical equilibrium. The numerical value of potential is defined in terms of the work which a body can do in virtue of its potential. In order to correlate this definition with what has been said in regard to the identity of potential with electrical pressure, imagine a large tank filled with water and having a small pipe of considerable length leading from its base along the ground. Consider the difference in the rate at which the water would leave the pipe according to whether the discharging end of the pipe was just below the level of the water, or whether the tank was raised high above the ground. The difference in level between the tank and the issuing water could clearly be defined in terms of the rate at which the water issued, or, what is more to the point, in terms of the work which the issuing water, in virtue of its pressure, could perform.

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* This statement requires some qualification, since the power to do work obviously depends upon the potential of other bodies. No body can be said to have an *absolute* value of potential, since the conception essentially involves the *difference* in relative condition of two bodies or points. For simplicity, the earth is assumed to be at zero potential, and the potential of any particular body is given a definite value, but this is merely a method of briefly stating that a difference, equal to that value, exists between the potential of the body and the potential of the earth.

CALCULATIONS IN ELECTRO-STATICS.

The fundamental facts and definitions upon which the numerical aspects of the various effects are dealt with may be briefly stated as follows:—

1. *Force is anything which changes or which tends to change* (a) *the state of rest, or* (b) *the uniform motion of a body.*

2. *The unit of force (the dyne) is such that acting for one second upon a gramme of matter generates a velocity of* 1 *centimetre per second.*

If a gramme of matter is allowed to fall freely under the force of gravity, its velocity at the end of one second is in London approximately 981 centimetres per second. A force equal to the *weight* of one gramme is therefore 981 dynes.

3. *Work (in ergs) is equal to the force in dynes multiplied by the distance (in centimetres) through which the force is overcome.*

4. *Unit quantity of electricity is such that when placed in air at a distance of one centimetre from a similar quantity it is repelled with unit force (one dyne).*

5. *Unit potential exists at any point when one erg of work is required to bring a unit of electricity of similar sign from an infinite distance up to that point in opposition to the force of repulsion.*

6. *The potential at any given point due to a charge is equal to the quantity of the charge divided by its distance from the given point.*

7. *The force of attraction or repulsion between two*

charges in air is equal to the product of their quantities divided by the square of the distance separating them.

8. *The capacity of a conductor or system of conductors is equal to the quantity of the charge divided by the difference of potential existing.* (*Vide* page 14 also.)

MAGNETISM.

The starting point in magnetic research was the discovery of an ore to which pieces of iron and steel would adhere. This ore received the name of "lodestone" and is now known to be the black oxide of iron (Fe_3O_4). It was next discovered that a piece of steel, after being rubbed with lodestone exhibited the same properties as the lodestone itself,—in fact, became what is now termed a permanent magnet.

The mariner's compass and the law governing attraction and repulsion between magnetic poles followed. The compass suggested that the earth itself is a magnet with its North and South poles approximately coincident with the North and South geographical poles. The actual position of the North magnetic pole is lat. 70° 5′ and long. 96° 46′ W., but it is believed that there are two South poles. A compass needle in London points about 16° west of the geographic North, but this value changes from year to year.

A piece of iron rubbed with lodestone exhibits little or no trace of magnetism when the magnet is removed. If, however, the lodestone is held in contact, the iron exhibits the properties of a magnet.*

LINES OF FORCE.

The disturbance created in the region of a magnet is termed a magnetic field and its strength is determined by the value of the force of attraction or repulsion which it exerts upon magnets.

Lines of force are hypothetical lines along which an isolated magnetic pole would move if perfectly free to do so. Such a pole cannot, of course, be obtained, and its existence is only postulated for the simplification of the reasoning. It may, however, be remarked that its use in dealing with the mathematical side of the subject is as frequent as it is valuable, and that the transition from the postulated pole to actual conditions is easily accomplished.

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* The molecular theory of magnetism is given in Appendix A (*q. v.*).

The directions of the lines proceeding from magnets are readily made apparent by sprinkling iron filings upon a sheet of paper or cardboard placed above the magnets. The lines of force in passing through the filings cause each one to become a magnet and to "line up" with its neighbours along the lines of force. It will, however, be noticed that the filings do not collect along the magnet itself, the reason being that iron and steel conduct lines of force far better than air and but few lines stray out of the metal into the surrounding air.

Every line of force is a closed curve, the direction of which is from South to North inside and North to South outside the magnet. Each line may be regarded as tending to repel the lines of force upon either side of it but having a tension along its length. Again, lines of force can never cross each other. Where such a tendency exists the lines repel each other and form separate and distinct curves. Every line of force tends to shorten itself, and where motion of a system is possible, that motion takes place in such a way as to render the lines as short as possible.

MAGNETIC INDUCTION.

The difference between a magnet and a piece of non magnetic material is, that the magnet possesses lines of force, whereas the non-magnetic material does not; also, that in the latter case lines passing through it do not render it magnetic, since its molecules are not magnets. If lines pass from right to left through a bar of iron, at the right-hand side of the iron there will be a South, and at the left-hand side a North pole. The statement is identical with that contained in the subsequent paragraph, and if the reader will draw a couple of bars in a straight line with each other—one representing a magnet and the other a piece of iron—he will, by filling in the directions of the lines of force due to the magnet, observe the direction in which they pass through the iron bar, and thus deduce the direction of the induced polarity of that iron bar.

Induction takes place along the lines of force, and *the induced pole is opposite in character to the inducing pole;* or, to give an example, a North pole approached to the right-hand side of an iron bar causes that end to become a South pole, the result being attraction. The attraction between a magnet and a piece of iron is, therefore, the result of previous induction. A line of force passes just as easily through brass, wood, glass, etc., as through air; hence the interposition of a piece of copper or other non-magnetic substance does not affect the action of the magnet. From that which has been already said on the subject of lines of magnetic force, it will be seen that the molecules of a magnetic substance arrange themselves along the lines, and that to magnetize a piece of steel the magnet should be stroked along in one direction only. The end at which the stroke ceases will be opposite in polarity to the pole with which the steel is rubbed.

QUANTITATIVE VALUES OF MAGNETIC EFFECTS.

The various calculations in regard to magnets are based primarily upon the definition of a unit magnetic pole, and for the use of more advanced students a few of the more important definitions and experimental facts are succinctly given below.

1. *A unit magnetic pole is such that when placed, in air, at a distance of one centimetre from a similar pole it is repelled with unit force* (*one dyne*).
2. *A magnetic field of unit intensity has one line of force per square centimetre passing through it; it acts on unit pole with unit force.*

The intensity of a magnetic field is defined in Gausses, a unit field being a field of 1 Gauss.

From definition 2 it follows that unit magnetic field (1 Gauss) exists at every point one centimetre from a unit magnetic pole of indefinitely minute size. In other words, 4π lines of force proceed from a unit magnetic pole and one of these lines passes through each square centimetre of the area of an imaginary sphere described, with a radius of one centimetre, around the unit pole.

3. *The force of attraction or repulsion (in dynes) between two magnetic poles is equal to the product of their strengths divided by the square of the distance separating them.*

As an example of the way in which these definitions may be employed, imagine that a magnet having a pole strength of 10 units and length 8 centimetres is placed with its nearer pole 5 centimetres from a magnetic pole of 3 units strength.

$$\text{Force due to nearer pole} = \frac{10 \times 3}{5^2} \text{ dynes.}$$

$$\text{Force due to more distant pole} = \frac{10 \times 3}{13^2} \text{ dynes.}$$

$$\text{Net effect on isolated pole} = \frac{10 \times 3}{5^2} - \frac{10 \times 3}{13^2} \text{ dynes.}$$

$$= 1{\cdot}02 \text{ dynes approx.}$$

The *moment* of a magnet is defined as the product of its pole strength and its length. A rough approximation to the result given above is contained in the statement that the force due to a magnet at a given point, in a straight line with it, is directly proportional to its moment and inversely proportional to the cube of the distance of the centre of the magnet from the given point.

VOLTAIC ELECTRICITY.

The arrangement termed a voltaic cell consists essentially of two dissimilar metals immersed in a liquid which will form a chemical compound with one of them, *e.g.* a piece of copper and a piece of zinc immersed in dilute sulphuric acid. For the present this primitive form of cell will serve the purpose of illustrating one method of producing the effect known as an electric current. The term "battery" will be used to describe a collection of cells properly connected together.

A copper wire joining the zinc and copper ends of a voltaic cell has properties which are not possessed by an ordinary piece of copper. These properties, which arise from the fact that the wire conveys an electric current,[*] are thermal and magnetic. If a cell of sufficient dimensions is employed in conjunction with a thin wire, the latter may be made incandescent. In every case heat *is* generated, but frequently the amount is too small to be measured or observed by any ordinary method. The magnetic effect is, however, far more readily shown.

A magnetic field exists round any wire carrying an electric current, and the lines of force will be found to lie in concentric circles with the wire as centre. This fact can be demonstrated by a current-conveying wire passing through a piece of glass or cardboard upon which iron filings are strewn. The general appearance of the filings, after tapping the glass or cardboard so as to enable the filings to settle into position, is indicated in Fig. 1.

An electric current has magnitude and direction. Its direction outside the cell is from the copper pole through the wire to the zinc pole, and the magnetic field created is always in strict accordance with the magnitude and direction of the current.

A few of the lines of force generated in a conductor bent into a loop are shown in Fig. 2, in such a manner that the relation between the direction of the current and the direction of the magnetic field produced is at once apparent.

A compass needle or a freely suspended magnet points to the magnetic North and South, and force is required to deflect it from that position. The best position in which the force can be applied so as to produce the maximum deflection is at right angles to the needle. A magnet, placed at right angles to the needle, *tends* to send lines of force straight across it, thus attracting one pole and repelling the other. If the earth's field were absent the compass needle would set itself along the magnet's lines of force, in precisely the same way that the compass needle normally sets itself along the earth's lines of force. When both fields are present the needle is urged by two forces at right angles to each other, and the position which it takes up depends entirely upon their relative magnitudes. If equal, then a deflection of 45° results.

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[*] The discussion as to what electricity may actually be is far beyond the scope of this work, but a reference to the source from which the trend of modern thought may be gathered will probably be useful to some readers The reference is *Journal of the Institution of Electrical Engineers*, Vol. XXXII., "Electrons," by Sir Oliver J. Lodge. See also *Matter and Energy*, by F. Soddy, Home University Library.

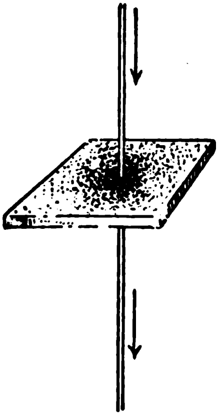

FIG. 1.—Iron filings round a current-conveying wire.

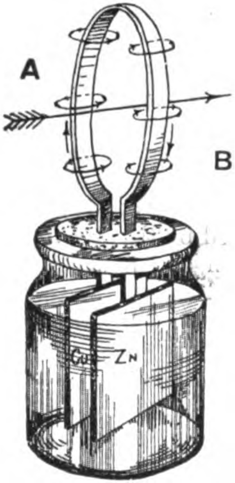

FIG. 2.—Illustrates the relation between the direction of a current and its magnetic field.

It has already been pointed out that, round a wire conveying a current, there are lines of force arranged in concentric circles at right angles to its length. Also that the difference between an ordinary piece of wire and one conveying a current is the absence of the magnetic field in the former case. If the current-conveying wire is placed in such a position that its magnetic field acts at right angles to that due to the earth, an alteration in the position of a compass needle placed at that point will result. The position in which the wire should be placed so as to produce the effect described is above or below, but in the same straight line as the needle. The wire's lines of force pass round the wire in planes at right angles to the length of the wire, thus *tending* to cut the earth's lines of force at right angles, and so produce a deflection of the needle.

It has been stated that where two magnetic fields whose directions when separately considered were at right angles to each other, the magnetic fields *tended* to cross one another. Lines of force can never cross each other, because the magnetic field at the point of intersection would, in that case, have two values, which is manifestly impossible. A current-conveying wire lying in the magnetic meridian directly above a compass needle causes the needle to be deflected. The field due to the earth is altered in its distribution by the field due to the current, and the needle sets itself in the direction in which the re-distributed lines now stand. In other words, a resultant magnetic field is produced by the action of the two separate fields and its direction and magnitude depend upon the values of the two fields.

By reversing the battery connected to the wire the direction of the lines of force due to the current is changed.

The direction of a line of force above a current-conveying wire is opposite to its direction below the wire (see Fig. 2), and therefore the direction in which a compass needle is deflected is dependent not only upon the direction of the current, but upon whether the wire is held above or below the needle. There are many rules for memorizing these effects, but three only will be given.

1. Mnemonic "**SNOW**," a current passing from **S**outh to **N**orth **O**ver the needle causes the North pole to be deflected to the **W**est.

2. Place the outstretched *right* hand between the wire and the needle, with the palm of the hand facing the needle, so that were the hand the wire, the current would flow from wrist to fingers. The outstretched thumb will then indicate the direction in which the North pole will turn.

3. Imagine a man swimming in the wire in the direction of the current, and that he turns so as to face the needle,

then the North pole of the needle will be deflected towards his left hand.

The converse of these rules, *i.e.* the determination of the direction of a current from the known direction in which a compass needle is deflected, is sufficiently obvious.

CONDUCTORS AND INSULATORS.

If the poles of a voltaic cell are joined by a dry piece of glass it will be found that no current exists. It is therefore clear that glass is a substance that will not permit the effect termed an electric current to take place along it. Such substances are termed non-conductors, or insulators, in contradistinction to conductors, and of all known substances silver conducts electricity most freely, whilst perfectly dry air is the best insulator. Electrical conductivity is, however, a matter of degree, for, whilst no substance conducts perfectly, it is certain that no substance is a perfect insulator. The best conductors are metals in the following order:—Silver, copper, gold, zinc, platinum, iron, tin, lead, and mercury. Next come carbon, acids, salt solutions, and water. Taking insulators in the same way the order is:—Dry air, glass, ebonite, paraffin wax, india-rubber, gutta-percha, silk, wool, porcelain, oils, paper, marble. This order is, however, subject to variations in accordance with the condition of the material.

The path along which a current flows is termed a circuit, and it is said to be completed when the current is passing.

UNITS.

Before electric currents can be compared standards must be defined in just the same way that the units of length, weight, and time, are defined in ordinary commerce.

Electromotive force stands in much the same relation to electricity as pressure does when applied to water. The different degrees to which various substances will permit the passage of a current has already been remarked. Another way of expressing the same fact is to say that some conductors offer more *resistance* than others.

A pipe of fixed size will deliver water at a certain rate when a given pressure is applied. An increase in the pressure or an increase in the size of the pipe will result in a corresponding increase in the flow of water through it. Similarly in an electrical circuit an increase in the electrical pressure or E.M.F., or a reduction in the resistance of the circuit will result in an increased value of *current.*

The units of current, electromotive force and resistance are as follows:—

Current	The ampere.
Electromotive force . .	„ volt.
Resistance	„ ohm.

THE OHM is represented by *the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice* (0° *C. or* 32° *F.*) 14·4521 *grammes in mass, of a constant cross sectional area, and of a length of* 106·3 *centimetres.*

This unit represents about the resistance offered by 80⅓ yards of the gutta-percha covered wire formerly used in joining up the instruments upon the tables in a telegraph office. It is the resistance offered by about 200 yards of 100-lb. copper line wire, or by about 132 yards of 400 lb iron line wire.

THE VOLT is represented by ·6974 ($\frac{1000}{1434}$) *of the electrical pressure at a temperature of* 15° *C. between the poles of the voltaic cell, known as Clark's cell,* set up in accordance with a detailed specification.

The E.M.F. of a Daniell cell is rather more than one volt, whilst that of the Clark cell is rather less than 1½ volts (actually 1·434 volts at 15° C.).

THE AMPERE is *the current which will flow through a circuit having a resistance of one ohm when urged by an electromotive force of one volt.*

Such a current will deposit silver from a solution of nitrate of silver in water at the rate of ·001118 of a gramme per second. This is the legal definition of a current of one ampere, and a specification is appended stating the details of the method of carrying out the determination.*

In telegraph practice the ampere is too large a unit, and it is therefore sub-divided into "milli-amperes," which, as the name implies, means thousandth parts of one ampere. This is usually denoted by the contraction "m.a.," and 1000 m.a. would therefore mean one thousand milli-amperes, or one ampere.

In order to avoid the constant writing of the words "ohm" or "ohms" after numbers the small Greek letter "ω" (omega) is used as an affix. Thus, "one hundred and fifty ohms" is written "150^{ω}." The capital letter has been similarly employed to represent "megohms," or millions of ohms, thus 10^{Ω} means 10 megohms or $10{,}000{,}000^{\omega}$. This convention is extremely useful in stating insulation resistances. which are usually of this order of magnitude.

For extremely small resistances such as the resistance between the opposite faces of a unit cube of metal or other highly conductive substances the "microhm," or one millionth of an ohm, is very frequently employed. For instance, the expression "165 microhms" therefore represents $\cdot 000165^{\omega}$.

OHM'S LAW.

Ohm discovered that the following relations existed between these units: ***The strength of current through any circuit varies directly as the electromotive force and inversely as the resistance***, or, stated in a more definite manner, the number of amperes flowing through a circuit is equal to the number of volts of electromotive force divided by the number of ohms of resistance in the entire circuit, or:—

$$\text{Current} = \frac{\text{Electromotive force}}{\text{Resistance}} \quad i.e.\ C = \frac{E}{R},$$

whence

$$R = \frac{E}{C}, \text{ and } E = C \times R,$$

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* The definitions of the three units, together with the specifications as to determination, are to be found in the *Electrician* of August 31, 1894, page 518.

where C, R and E are respectively the current, resistance, and electromotive force in the circuit.

For instance, an E.M.F. of 12 volts applied to a circuit of 6 ohms resistance will produce a current of $\frac{12}{6} = 2$ amperes. If the E.M.F. in a circuit be 30 volts and the current 10 milli-amperes, its resistance must be $\frac{30}{\cdot 010} =$ 3000 ohms. If the current is 2 amperes and the resistance is 10 ohms, then the E.M.F. in the circuit will be $10 \times 2 = 20$ volts. These quantities should *all* be expressed in volts, amperes, and ohms.

OTHER ELECTRICAL UNITS.

From the three units of current, E.M.F., and resistance, the remaining electrical units may readily be derived and, although detailed treatment is scarcely possible in a work of this description, it is undesirable entirely to omit them since there are many cases in which their use is essential.

THE COULOMB *is the unit of quantity of electricity and may be defined as the quantity of electricity which would pass any given point in a circuit carrying an unvarying current of one ampere in one second.*

THE FARAD *is the unit of capacity and represents the capacity of a condenser which at a pressure of one volt would be charged with one coulomb of electricity.*

Relationships analagous to Ohm's law exist between E.M.F., quantity, and capacity. They are:—

$$\text{Difference of potential} = \frac{\text{Quantity}}{\text{Capacity}}$$

$$\text{Capacity} = \frac{\text{Quantity}}{\text{Difference of potential}}$$

$$\text{Quantity} = \text{Difference of potential} \times \text{capacity.}$$

If a condenser of ·001 farad capacity has a charge of ·2 coulombs the difference of potential across its terminals is $\frac{\cdot 2}{\cdot 001} = 200$ volts.

As an example of the second relation, suppose that the quantity of electricity in a condenser is ·01 coulomb whilst the difference of potential across its terminals is 50 volts. The capacity is then $\frac{\cdot 01}{50} = \cdot 0002$ farad.

The third form of the relation is illustrated by ascertaining the charge in a condenser of, say, ·00002 farads capacity due to the application of an E.M.F. of 50 volts. It is $50 \times \cdot 00002 = \cdot 001$ coulomb.

The values of the capacity chosen in these examples have been extremely small fractions of the unit, the farad, but even these fractions are far larger than are met with in the case of long aërial or even short underground telegraph circuits, consequently a subdivision of the farad, the microfarad, is employed in practice. It is equal to one millionth part of one farad and is usually denoted by the affix "m.f."

An example of a case occurring in telegraph practice is that of a shunted condenser (*q. v.*). If an E.M.F. of 30 volts is applied to a condenser of 3½ m.f. capacity the value of the charge will be $\frac{30 \times 3\frac{1}{2}}{1{,}000{,}000} = \cdot 000105$ coulomb.

One microfarad is the capacity of about three miles of a telegraph circuit consisting of a gutta-percha covered wire laid in pipes in the earth. It is the average capacity of about 70 miles of 100-lb. copper wire erected upon poles and of 8 miles of 40-lb. conductor screened cable laid underground.

The phenomenon of self-induction is simple and capable of easy explanation, but the complete definition of the value of the inductance of a circuit is somewhat complex.

Wherever a current exists there is a magnetic field. This field is the result of the current, and in coming into existence it cuts through the current-conveying conductors to which it owes its origin. Now wherever a magnetic field cuts a conductor or *vice versa* an E.M.F. is generated. Imagine a battery or other source of E.M.F. applied to a coil of wire such as that shown in Fig. 48. The current does not instantly attain its full value, since its rise is opposed by the E.M.F. generated by the lines of force cutting through the conductors. This opposing E.M.F. is termed the "back E.M.F." of self-induction. If, now, the coil and battery are short-circuited, a current will flow through the circuit in the same direction as the original battery current. This is caused by the collapse of the lines of force which, in so doing, cut through the conductors in the opposite direction.

THE HENRY is the unit of inductance, and represents *the inductance of a circuit in which a counter E.M.F. of one volt is generated when the value of the current changes at the rate of one ampere per second.*

One or two general remarks may be made upon this definition, but detailed treatment is altogether beyond the scope of the present work.

If a bar magnet is plunged into a coil of wire the magnet's lines of force cut through the windings of the coil and an E.M.F. is thereby generated. The value of this E.M.F. is directly proportional to (i) the strength of the magnetic field, (ii) the rate of motion, and (iii) the number of convolutions.

The magnetic field generated in a coil of wire by passing a given current through it is proportional to the number of convolutions. By doubling the number, the magnetic field is doubled, and this doubled field will, when the current is stopped or started, cut the windings, which are twice as many as in the former case, and thus generate four times the E.M.F. If the convolutions are quadrupled the quadrupled magnetic field cuts the quadrupled turns, so generating sixteen times the E.M.F. It will therefore be apparent that the inductance of a coil of wire is proportional to the *square* of the number of turns of wire.

The inductance of an electromagnet varies somewhat with the value of the current employed, because the magnetic field generated in the core depends upon the degree or intensity of the magnetization of the iron and is not in direct ratio to the magnetizing force. Hence in stating the inductance of a relay, for instance, the value of the current is stated. The inductance of a P.O. standard "A" relay is 3·55 henrys, and of a "B" relay 3·74 henrys with their coils in series for a current of 20 m.a. The inductance when small in value is often expressed in thousandths of a henry or in milli-henrys.

The inductance of a relay with its coils in parallel is one-quarter of its value with its coils in series, since the effective number of turns is one-half in the former case.

The units of power and energy may be given to complete the list of practical units. *The watt is the rate at which work is done when one ampere flows through a conductor with a difference of potential of one volt across the ends of the conductor.*

$$\text{Watts} = E \times C \text{ or } C^2 \times R \text{ or } \frac{E^2}{R}.$$

A *Kilowatt* is equal to 1000 watts.

A 25 candle power incandescent lamp requiring ·13 ampere upon a 230 volt circuit therefore takes 230 × ·13 = 30 watts. As 746 watts is equal to one horse-power, the lamp is taking approximately $\frac{1}{25}$ of one horse-power.

The commercial unit in which electrical energy is sold by electrical undertakings is known as the Board of Trade unit and is the practical unit of energy. *The Board of Trade unit is equal to* 1000 *watt-hours,* i.e. 1·34 *horse-power for one hour.*

Twenty of the lamps mentioned above would consume 600 watts, and if burning for three hours the energy used would be 600 × 3 = 1800 watt-hours or 1·8 B.O.T. units.

CHAPTER I

PRIMARY CELLS

AN electric current represents a certain amount of energy. It is not in the power of man to *create* energy, but the energy with which the world is endowed may be applied to effect desired ends. A voltaic cell may be defined as a piece of apparatus which converts chemical energy into electrical energy. A cell supplies electrical energy, in the shape of an electric current, by taking an amount of chemical energy, equal to the electrical energy, from the constituent parts of the cell.

In the simple cell previously mentioned the sulphuric acid attacks the zinc, and with it forms a chemical compound known as sulphate of zinc. If, however, a cell of this description is put to practical uses, it will be found that the current grows rapidly weaker, until at last it almost ceases. The reason is that the hydrogen, which is liberated in the re-arrangement of the chemical compounds, forms a layer of gas over the copper plate. Again, the impurities in the zinc, such as iron, tin, arsenic, etc., combine with the zinc to form little batteries, and waste it away without any equivalent of work done in the external circuit. This evil is known as *local action.* The words "external circuit" are used in contradistinction to the "internal circuit," or path of the current inside the cell itself. The troubles to which the impurities in the zinc give rise are eliminated by the process known as *amalgamation*, which consists in coating the zinc with mercury, thus making it behave as though it were chemically pure.

Although this remedy has been known since 1828 the theory of its action is still undecided. It has been suggested that, since zinc amalgamates so readily, the zinc at once passes to the surface of the amalgam, whereas the impurities, being less readily amalgamated, do not pass to the surface. The amalgam would thus act as a filter, but as soon as it became thin the impurities would project and local action result, which is found to be the case.

This view of the matter is satisfactory so far as the impurities are concerned, but it fails to explain the absence of local action between the zinc and the mercury.*

The accumulation of the hydrogen upon the negative element is not so easily remedied. The thin coating of this electro-positive gas gives rise to what is termed "polarization," and its effects are most deleterious.

The surface of the plate being covered with hydrogen reduces the area in contact with the liquid, which increases the internal resistance of the cell (see Chapter II). Also, and this is by far the more serious aspect of the question, hydrogen is electropositive, and therefore tends to re-combine with the zinc sulphate and so to deposit zinc upon the negative element. The statement of this tendency is another way of saying that an E.M.F. is set up in opposition to the prime E.M.F. of the cell. The E.M.F. of the cell under such conditions is seriously decreased. In a simple cell such as that considered it was found that the E.M.F. fell from ·85 volt to ·54 volt in one minute after its terminals were joined through a resistance of 10^{ω}, and to ·355 volt at the end of five minutes. It will therefore be realized how serious a matter polarization becomes, and that its prevention is imperative if anything which even remotely resembles a steady current is to be obtained.

The E.M.F. of any particular type of cell is independent of its dimensions, but its internal resistance is dependent upon them, and generally speaking the larger the cell the lower is its internal resistance, and also the greater is the amount of electrical energy which may be obtained for a single charge. These points are, however, reverted to in Chapter II.*

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* *Primary Batteries*, by W. R. Cooper.

Although it has been noted that the hydrogen liberated during the action of the cell is deposited upon the negative element, the way in which this occurs has not yet been dealt with. The hydrogen does not pass from the positive element through the electrolyte in the form of bubbles. Upon being liberated by the combination of zinc with the sulphuric acid it immediately combines with the SO_4 of an adjacent molecule of H_2SO_4, thus liberating the hydrogen from this molecule. The action is repeated across the liquid until the negative element is reached, when the hydrogen comes off in the form of visible bubbles. No sign of the action is to be seen in the liquid which intervenes between the two elements of the cell.

It has already been stated that zinc is the negative and copper the positive terminal of the cell under consideration. In the external circuit the current flows from copper to zinc, but in order that the circuit may be complete (without which there can be no current) the current must flow from zinc to copper *inside* the cell, hence to express both facts the *zinc* is termed the *positive element*, but the *negative pole* or terminal of the cell. Similarly the *copper* is the *negative element*, but the *positive pole*.

The positive metal or element is always the one which is acted on or consumed by the liquid. The liquid which consumes the zinc, when the circuit is completed, is called the *excitant*, as opposed to the liquid or substance taking up the hydrogen, which is called the *depolarizer*. The hydrogen causes polarization unless means are employed to get rid of it, or, in other words, to *de*polarize the cell.

LECLANCHÉ CELLS.

The containing vessel of this cell (Fig. 3) consists of a square glass jar, ending in an almost circular collar, shaped to admit the zinc rod which forms the positive element. The rod is cast on to a copper wire, which is usually insulated where it emerges from the zinc and forms one terminal of the cell. The collar and a portion of the jar itself are usually very heavily coated with ozokerit to arrest the creeping of the salt. Inside the jar is placed a circular porous pot containing the negative element, a carbon plate, and the depolarizer, manganese dioxide.

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* At this point readers who have little or no knowledge of chemistry are advised to read carefully Appendix B on chemistry.

Hitherto, it has been laid down as an essential condition that the form of the manganese dioxide termed "pebble" should be used, and that it should be free from dust. But it has been discovered by J. G. Lucas * and proved by exhaustive researches that the best results are obtained by using powdered commercial manganese dioxide which will pass through a sieve 50, but not through a sieve of 60, meshes to the inch.

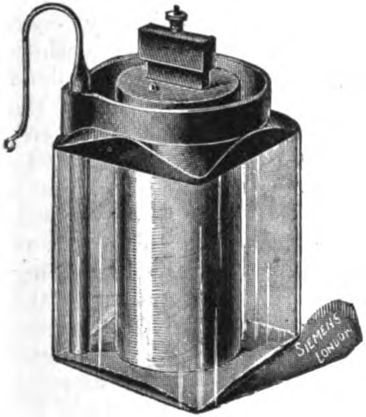

FIG. 3.—Porous pot form of Leclanché cell.

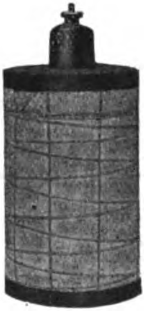

FIG. 4.—No. 0 "Sack" Leclanché Element.

The top of the carbon plate is capped with a heavy lead lug carrying a brass terminal. In order to arrest injurious affection of the lead lug and its terminal, the lug and a small part of the upper portion of the plate are thickly coated with paint. The top of the porous pot is sealed over with the carbon plate in position.

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* "Life and Behaviour of Primary Batteries used for Telephone Purposes," by J. G. Lucas. Paper read before the Institution of Post Office Electrical Engineers on December 12, 1910.

The exciting fluid is a saturated solution of salammoniac (ammonium chloride) contained in the outer jar.

As will be seen when considering the chemical actions which take place during the discharge of a Leclanché cell, free ammonia gas (NH_3) is generated, and this has a deleterious effect upon metal work and upon the acid solution in adjacent secondary cells in the battery room. The evolution of this gas necessitates free ventilation in any battery compartment which may be used, and evaporation of the solution is therefore facilitated. In order to permit a cell to be sealed, with the object of thereby retarding evaporation of the solution, manganese chloride is substituted for ammonium chloride in the case of batteries where the time of discharge extends over several months. With the manganese chloride excitant no free gases appear to be evolved. The effect of using manganese chloride is to produce a slightly higher E.M.F.

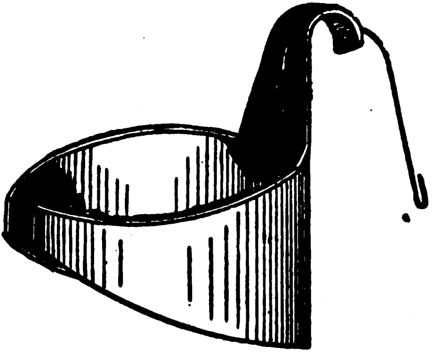

FIG. 5.—Shallow circular zinc.

It is essential that the porous pot shall be wet, in order to permit the passage of the current through the cell. Therefore a certain amount of water or a weak salammoniac solution is added to the porous pot. The latter is a much better conductor than the former.

The cells are usually made in four sizes, known as No. 0, No. 1, No. 2, and No. 3 sizes. The sizes employed by the Department are Nos. 0, 1, and 3, *i.e.* the four-pint, three-pint, and one-pint sizes respectively.

A large circular zinc plate surrounding the porous pot was formerly employed with the No. 1 size, but gave place to the shallow circular zinc illustrated in Fig. 5. The large zinc plate was found to be very wasteful, as the current is not equally distributed throughout the area of the zinc, the result being that it is worn away very unevenly. A hole occurs about an inch and a half from the bottom, and also at the top of the liquid. By experiment it was found that the zinc could be reduced to the form mentioned without any undue increase in the resistance of the cell.

Further, J. G. Lucas has, in his historic paper, called attention to the fact that the resistance of a Leclanché cell does not vary in proportion to the size of the zinc used. In a typical experiment it was found that a Leclanché cell with a circular zinc having an area of 30 square inches immersed in the solution gave an internal resistance of ·86$^{\omega}$, and with a rod zinc with an immersed area of 8 square inches an internal resistance of but ·96$^{\omega}$, whilst on reducing the immersed area to 4 square inches the resistance was raised only to 1·05$^{\omega}$. The explanation of these results lies in the fact that the major part of the internal resistance of the cell lies between the outside of the porous pot and the carbon. In the case cited this would amount to about ·75$^{\omega}$, and it will therefore be recognized it would not be possible solely by increasing the size or area of the zinc to reduce the resistance of the cell below this figure. For No. 0 cells two rods are used.

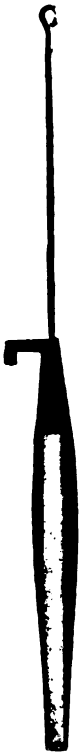

FIG. 6.—Leclanché cell taper zinc rod. (Siemens.)

A typical zinc rod is shown in Fig. 6. It has been found that a tapered zinc of this shape is more economical than the ordinary type of rod.

In making up the cell with powdered manganese dioxide, the latter should be moistened with water or with a weak solution of salammoniac, and tamped as firmly as possible in position in the porous pot so as to form, practically, a solid mass around the carbon plate. When this is done there is no difficulty in obtaining as low an internal resistance as ·5ω with the No. 1 size of cell equipped with a rod zinc. It need only be added that in no type of Leclanché cell is there any appreciable local action.

The powdered manganese cell is far more efficient than the agglomerate types of cell in which the porous pot is dispensed with by making up the depolarizer in slabs or rods secured to the carbon. In the Sack form of cell the porous pot, the only function of which is to maintain the depolarizer in intimate contact with the carbon, is replaced by a wrapping of textile fabric reinforced by a string lapping (Fig. 4).*

Chemical Action.—When the cell is thus made up there will be no action whatever, as the salammoniac will not attack the zinc, in fact will not have the slightest effect on it when the circuit is not closed. When the circuit is closed, the chemical compounds are entirely altered in their distribution. Salammoniac is a compound of ammonium and chlorine, and is represented by NH_4Cl (one atom each of nitrogen and chlorine, together with four atoms of hydrogen). When the circuit is closed, the zinc and the ammonium in the salammoniac change places, and thus part of the zinc will be consumed to form zinc chloride (a substance that readily dissolves in the salammoniac solution), ammonia gas (which combines with water to form ammonium hydrate NH_4HO) and hydrogen which is set free. This hydrogen, which appears at the carbon plate, must be removed in order that it may not give rise to polarization. The depolarizer used in the Leclanché cell is, as previously stated, the manganese dioxide packed round the carbon plate. Immediately the hydrogen is liberated it combines with the oxygen of the manganese to form water. The action may be stated thus:—

Outer cell:—

	Zn	$+$	$2NH_4Cl$		
	One molecule of zinc	together with	two molecules of salammoniac		
$=$	$Zn\,Cl_2$	$+$	$2NH_3$	$+$	H_2
form	one molecule of zinc chloride	together with	two molecules of ammonia gas	and	two atoms of hydrogen.

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* The Daniell, Bichromate, and Agglomerate cells, which are now obsolete, are described in the earlier editions of this work.

Inner Cell :—

H_2	$+$	$2MnO_2$	$=$	Mn_2O_3	$+$	H_2O
Two atoms of hydrogen	**and**	two molecules of manganese dioxide	form	one molecule of manganese sesquioxide	and	one molecule of water.

In the inner cell it will be seen that the two molecules of manganese dioxide taking part in the reaction have between them given up one atom of oxygen to the hydrogen, thus forming water. On the other hand, the two molecules of manganese dioxide have become one molecule of a lower oxide, namely, Mn_2O_3, the sesquioxide of manganese.

Dry Cells.

A dry cell may be defined as a cell in which the exciting and depolarizing materials are applied in the form of thick damp pastes, which in comparison with the fluid electrolyte of an ordinary cell perhaps justifies, or, at all events, extenuates, the generic title given to this class of cell. If, however, the pastes were actually dry the cell would, by reason of its enormously high internal resistance, be incapable of supplying a current. As a matter of fact cells frequently fail after some little service because they dry up—a condition indicated by a rapid rise in internal resistance.

Every dry cell is a modification of the Leclanché cell and has precisely the same electro-chemical reactions, a fact which is definitely established by the equality of the E.M.F.s of the Leclanché and dry cells.

All cells consist of a zinc containing vessel from 13½ to 22 mils. in thickness, with a carbon plate or rod, either cylindrical or fluted, to give greater area of contact with the depolarizer. The carbon is either insulated by a layer of paper or given a half-inch clearance from the bottom of the zinc vessel. The general composition of the two pastes is 10 lbs. of MnO_2, 10 lbs. of carbon or graphite or both, 2 lbs. of NH_4Cl, 1 lb. of $ZnCl_2$, and sufficient water to give the proper amount of electrolyte to the cell. Various additions are made by the manufacturers, such as starch or other forms of paste, with a view to improving the contact between the zinc and the white or exciting paste, and to promote action throughout the charge. The efficiency of the cell depends very largely upon the purity of the charging materials and upon its contact with the conductive carbon.*

The Siemens Dry Cell (Figs. 7 and 8). This cell has been chosen for detailed description as typical. It consists of a zinc cylinder of a thickness suitable to the size of the cell, with a connection wire attached to the inside of the cylinder. This latter contains a carbon rod, surrounded by a depolarizer, composed of a mixture of powdered peroxide of manganese and carbon intimately mixed and pressed into close contact with the carbon rod. A brass terminal is fixed into the top of the carbon in the following manner:—A vertical hole is provided in the rod into which the pin of the terminal is inserted, and a molten alloy, composed of bismuth, lead and tin, is poured around the pin. As this alloy expands slightly in cooling, it establishes a per-

Fig. 7.—Siemens dry cell.

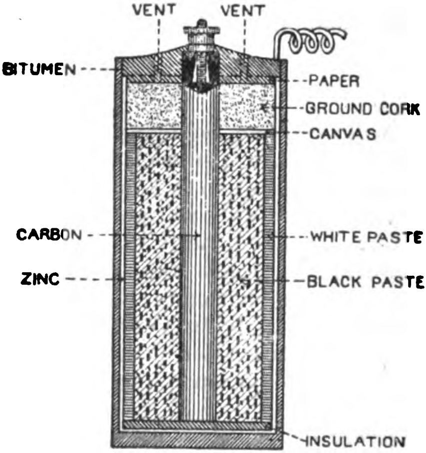

Fig. 8.—Section of a Siemens dry cell

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* American Electrochemical Society, paper "Certain characteristics of dry cells," by C. F. Burgess and C. Hambuechen: *Electrician*, August 12, 1910, p. 743.

fect contact between the pin and the carbon. An exciting paste composed of plaster of Paris and flour mixed with a solution of ammonium chloride surrounds the depolarizer. A space is provided in the upper part of the cell to receive the gases and water which are formed during the working of the cell, and this space is filled with ground cork as an absorbent for the moisture. The cell is sealed at the top with a layer of bitumen. Small holes are provided for the escape of the gases; their utility is somewhat doubtful since, if effective, they would carry off the moisture and so cause the cell to dry up earlier than it does. The cell is contained in a strong cardboard box impregnated with paraffin wax, which makes it damp-proof, and thus insulates the cell.

Other Dry Cells. The E.C.C. cell has a flat carbon plate, and contact between the carbon and the bottom of the container is averted by covering the bottom with a layer of insulating material. In the Hellesen cell the negative element is a hollow circular carbon, the interior of which is filled with silicated cotton.

Dry cells in two sizes are in general use by the Post Office, viz. "Y," the circular cell of about 40 ampere-hours capacity, and the large square "Z" cell with a capacity of 140 ampere-hours. A very small square cell is employed for testing purposes and for the speaking battery on portable telephones.

STANDARD CELLS.

A particular combination of materials in a cell will always produce the same E.M.F. provided the materials are exactly alike. In the form of cell invented by Latimer Clark it is a *sine qua non* that all the materials employed shall be chemically pure. Under these conditions the E.M.F. of the cell is 1·434 volts at 15° C. The cell is usually very small, and is often made in a short wide test tube. Into the bottom of the test tube a short piece of platinum wire is fused. The outer part of this wire forms the positive terminal and the inner serves to make connection with the negative element, metallic mercury, which covers it. Above the mercury a thick paste of mercurous sulphate is spread, and above this is a paste of zinc sulphate into which the zinc rod dips. The zinc rod passes through the cork or bung, and the whole arrangement is sealed up.

The chemical action of the cell is due to the SO_4 of the exciting fluid (zinc sulphate) combining with the positive element to form zinc sulphate and liberate zinc which combines with the mercurous sulphate to form zinc sulphate and mercury. The mercury so formed merely adds to the quantity already present. There is a very large number of modifications of the Clark cell in existence, but in principle they do not vary at all. The final form given to such a cell is illustrated in Fig. 10, and it will be noticed that a thermometer has been added for ascertaining the temperature of the cells, since this has an important influence upon the value of the E.M.F.

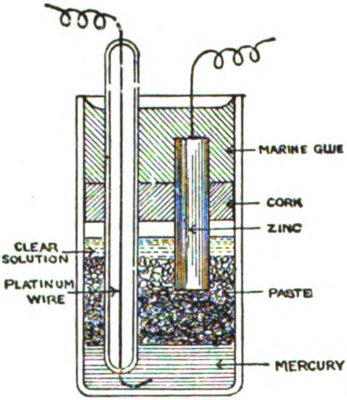

FIG. 9.—Clark standard cell (full size).

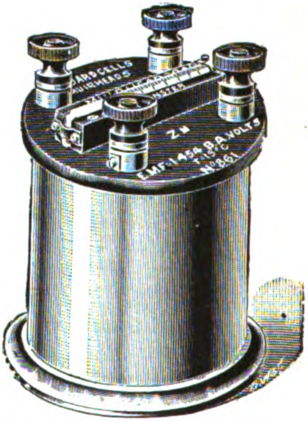

FIG. 10.—Pair of Clark cells and thermometer.

A full size section of a cell is shown in Fig. 9, whilst the subsequent figure shows the general appearance of a pair of cells mounted in the usual way with a thermometer.

The Board of Trade specification for the preparation of the cell details the manner in which the materials of the cell shall be prepared. It directs that the zinc and mercurous sulphates shall be mixed together in the form of a paste and ensures the formation of saturated solutions of zinc and mercurous sulphates in water.

DANIELL STANDARD CELLS.

Modifications of the Daniell cell have been used by some physicists with excellent results, but its use has not been very extensive.

A standard cell which is required for accurate work should only be used to produce a current through very high resistances, *i.e.* resistances of the order of 100,000 ω. Even then the current should only be maintained for the shortest possible time. Neglect of these precautions entails inaccuracy in the value of the assumed E.M.F.

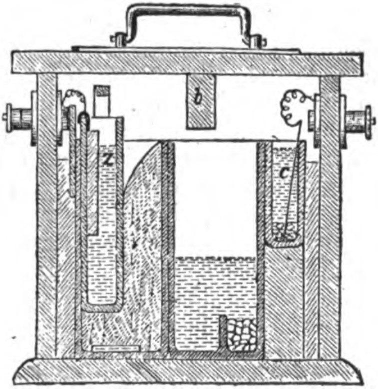

FIG. 11.—P.O. form of standard Daniell cell.

Where the highest accuracy is not essential less delicate apparatus may be employed. For example, the P.O. tangent galvanometer requires far too large a current to produce a satisfactory deflection with such a cell as Clark's. To provide a standard E.M.F. and one capable of supplying a current of a milli-ampere the P.O. standard Daniell was designed and for many years was extensively employed by the Department. This cell, though far less accurate than a Clark cell used under the best conditions, was sufficiently so for its purpose. The zinc and its porous pot (Fig. 11) were kept in one compartment and the copper in another, and the parts of the cell were only assembled when the cell was actually in use. The lid carried a projection which made it impossible to close the cell until the porous pot containing the zinc and the copper plate had been replaced in their receptacles.

Special care was taken that the constituent parts of the cell and the chemicals employed were as pure as possible. The exciting fluid was a saturated solution of zinc sulphate. This cell was replaced by a dry cell whose E.M.F. was periodically measured by accurate apparatus. (See Chapter III).

CHARACTERISTICS OF CELLS USED BY THE POST OFFICE.

The E.M.F. of a cell decreases and the internal resistance rises as the cell becomes exhausted, and it is therefore necessary to define the point at which the cell should be considered faulty. Again, bad materials or defective porous pots adversely affect the E.M.F. and internal resistance. A pot which is of a too porous character permits the excitant and depolarizer rapidly to commingle. This does not apply in the case of Leclanché cells, and a minimum resistance is not specified. A very hard one, on the other hand, unduly increases the internal resistance of the cell. Cells are considered faulty if their E.M.F.s fall below the minimum value given in the table upon page 32. They are also considered faulty if their internal resistances rise above the maximum or fall below the minimum value; the latter is usually due to the porous pots being too soft.

Leclanché cells with granular manganese dioxide polarize if heavily worked, since the hydrogen appears at the carbon plate more rapidly than the manganese can dispose of it. With intervals of rest or for small currents the cell possesses many advantages, notably the entire absence of local action when not in use, and the very small amount of attention necessary.

On the other hand, Leclanché cells charged with powdered manganese dioxide are comparatively steady. In this connection some extraordinary results are given by J. G. Lucas; for example, a Leclanché cell made up with *granular* manganese dioxide was discharged for five hours per day, six days per week, at a mean current of 41·6 m.a. until the voltage had fallen to 1^v, by which time 7 watt-hours were obtained. A similar cell, excepting that it was charged with *powdered* manganese dioxide, was discharged under the same conditions and gave 77·5 watt-hours before the voltage had fallen to 1^v. At higher current discharge rates the disparity between the two types is shown to be even greater. At a discharge rate of 100 m.a. the powdered manganese dioxide cell gave an output 15 times greater than the granular dioxide cell, and at ·5 ampere, 30 times greater.

Two cells with granular dioxide were discharged at a mean rate of 41·6 m.a., and 7 watt-hours were obtained by the time the voltage had fallen 33 %. The manganese dioxide in both cells was emptied from the porous pots and the contents of one of them was ground to powder. The materials were then restored to their original porous pots and the cells again discharged separately at approximately the same discharge rates as originally. The cell in which the granular contents had been restored gave a further 1·155 watt-hours by the time the voltage had fallen to $·95^v$, whilst the cell in which the manganese dioxide had been restored in a powdered condition gave a further 56 watt-hours before the voltage had fallen to the same value.

The Daniell cell is remarkable for the very small amount of polarization which occurs, even when heavily worked. It is also notorious for the very considerable amount of local action which always occurs. Its comparatively low E.M.F. and high internal resistance render it unfitted for purposes where heavy currents are necessary. The small size was formerly employed for simplex sounder circuits, whilst the large size was used for ordinary duplex circuits and for local batteries generally. Owing to its local action and the more frequent attention required it would not be as satisfactory as the Leclanché cell for single-needle and double-plate sounder stations.

The Bichromate cell was used wherever large currents, sustained for considerable periods, were required. It is most efficient when it is heavily worked, but owing to the frequent and skilled attention required it is unsuitable for general use. It also suffers from local action, as a result of diffusion of the solution through the porous pot.

Type of Cell.	E.M.F. (volts).		Internal resistance (Ohms).		Purpose for which used.
	Max.	Min.	Max.	Min.	
Bichromate . .	2·16	1·836	4	2	Superseded by modified Leclanché types.
Daniell	1·08	·972	4	2	
New Leclanché No. 0 (with two zinc rods)	1·55	1·0	2	—	Quadruplex, High speed, Long duplex, Universal, and Central battery telegraph systems.
,, ,, No. 1	1·55	1·0	2	—	Sounders simplex and duplex. Local batteries generally.
,, ,, No. 3	1·55	1·0	3	—	Telephone speaking batteries, D.P.S., Single needle and for minor purposes generally.
Dry cells . . .	1·55	1·0	3	—	Special arrangements.

It may be remarked that the internal resistance of a battery affects the speed of working of a circuit (*vide* Chapter XIX). If too low the transmitter sparks, whilst too high a value reduces the working speed. To obtain an E.M.F. of 100^{v}, 105 Daniell cells would be required as against 55 Bichromate cells. The internal resistances in the two cases would be from 110^{ω} to 220^{ω} with Bichromates, and from 210^{ω} to 420^{ω} with Daniells.

Dry cells possess the advantage of portability and are eminently suitable for special arrangements. Indeed, they may be employed for almost any purpose. Since the internal resistance is very low a 10^{ω} resistance coil is placed in every 10-cell box, so that excessive currents may not be produced. If the 10^{ω} coils were omitted when the cells were used in conjunction with a Wheatstone transmitter, the excessive sparking would at once put the transmitter out of action.

IDEAL CELL.

There is no form of primary battery which fulfils all the conditions one would desire from an ideal point of view, and therefore it happens that the choice of a battery largely depends upon the uses to which it is to be put. An ideal cell should possess the following characteristics:—

1. High E.M.F.
2. Low internal resistance.
3. Absence of polarization.
4. Absence of local action.
5. Cost of the cell small.
6. Cost of charging small.
7. Amount of energy per charge should be large.
8. Attention required should be little.
9. No injurious fumes should be given off.
10. The materials should be easily and safely handled.
11. Dimensions as small as possible.

Conditions 6 and 7 mean that the cost of a given quantity of electrical energy should be as low as possible, and conditions 7 and 8 specify that the labour cost of maintenance shall be small.

Leclanché cells charged with powdered manganese dioxide more nearly approach these ideal conditions than either the Daniell or the Bichromate cells. Moreover, owing to the low internal resistance of the modified cell the more costly agglomerate cells are likewise being superseded. Indeed, the only types of cell which are now used for general purposes will be (i) the modified Leclanché with rod zincs, in three sizes, viz., the No. 0, No. 1 and No. 3, (ii) the dry cell in two sizes, viz., Y and Z, and (iii) secondary cells.

The No. 3 size will be used for (i) telephone speaking batteries—it having been found that an internal resistance not exceeding 3^{ω} per cell makes no appreciable difference in the speaking efficiency—and, (ii) for all minor telegraph, and telephone signalling, purposes. No. 1 cells will be used for sounder circuits, simplex, duplex and local batteries generally. The No. 0 size, provided with two zinc rods, will be used for high-speed Wheatstone, quadruplex, and long duplex, circuits, universal and small central battery telegraph systems. Dry cells will only be employed in lieu of porous pot cells when the latter cannot be used for reasons affecting portability or accommodation in exceptional circumstances.

CHAPTER II

CALCULATIONS IN CONNECTION WITH CIRCUITS AND CONDUCTORS.

PART I.—ARRANGEMENT OF CELLS.

SIZE OF CELLS.

THE E.M.F. of a cell is entirely independent of its dimensions, so that a cell consisting of a grain of zinc and a percussion cap would have just the same E.M.F. as a cell composed of the same materials, but as large as a Lancashire boiler. The internal resistances in these two cases would differ very widely, as also would the amount of electrical energy obtainable from each. The quantity of energy obtainable from any cell is the product of its average E.M.F., its average current, and the time that it supplies that current. The actual value obtained will differ considerably according to the conditions chosen.

The method adopted by the Post Office takes account of the differences in the dimensions of the various cells tested. It will be obvious that, given two cells of similar type but of different size, the larger cell will furnish a given current for a longer period than the smaller one. Not only so, but, at any period during the discharge, the larger cell is subjected to a less severe test, since its resources, *i.e.* the quantities of active material, are much greater.

The capacity of the various sizes of modified Leclanché cell in ampere-hours decreases, as with every other type of cell, as the current discharge rate is increased. The extent of the variation is indicated in the table in the case of the No. 1 cell.

The method of testing consists in discharging the cell for 5 hours per day, 6 days per week, through a $CuSO_4$ electrolytic cell at a mean rate corresponding to the size of the cell (*e. g.* 50 m.a. for a No. 1 or a Y dry cell). The ampere hours are computed from the increase in the weight of the copper cathode of the electrolytic cell.

Contrary to the behaviour of Leclanché and other wet cells, however, the tendency of the ampere-hour capacity of the dry cell is to decrease as the discharge rate is decreased owing to the fact that with a small discharge rate the period of discharge must necessarily extend over long periods. The cells therefore tend to dry out, and this entails their rejection owing to high internal resistance before the elements can be fully utilized. There is therefore a discharge rate for dry cells at which they give maximum output. For, if the current be increased the output is decreased owing to polarization effects. This is indicated by the two results given in the case of each size of dry cell used by the Post Office.

AMPERE-HOUR CAPACITY OF CELLS.

(Cells discharged at rates given for 5 hours per day, six days per week, until E.M.F. has fallen to 1^{v}.)

Type of cell.	Capacity in ampere-hours.	Discharge rate m.a.	Type of cell.	Capacity in ampere-hours.	Discharge rate m.a.
No. 0	120	100	No. 3	20	20
,, 1	80	20	Dry Y	40	50
,, 1	76	40	Y	42	42
,, 1	66	80	Z	140	100
,, 1	48	160	Z	148	90
,, 1	36	320			

The internal resistance of a cell is only roughly proportionate to its size when the cell is of homogenous construction. In the case of the simple zinc-copper-dilute sulphuric acid cell, for example, the rule holds good, but in case of the Leclanché and dry cells an increase in the size of the cell means that, although the areas of the conducting surfaces are increased, the distance between the zinc and carbon plates is also increased, and the resistance therefore tends to remain uniform. The relationship between area and distance will be fully understood after consideration of the principles enunciated upon page 56.

The Post Office standard of maintenance is (i) a maximum resistance of 3^{ω} per cell for the No. 3 size, and 2^{ω} for other sizes and types inclusive of the Y to Z sizes of dry cell, and (ii) a minimum unit of 1 volt at any period of the normal discharge.

THREE METHODS OF JOINING-UP CELLS.

There are three ways in which cells may be arranged, firstly in series, secondly in parallel, and thirdly in parallel-series or multiple arc, this method being a combination of the first and second methods.

CELLS IN SERIES.

The series method consists in connecting the copper of the first cell to the zinc of the second cell, and connecting the copper of the second to the zinc of the third, leaving the latter's copper pole free. The zinc of the first cell and the copper of the last cell form the poles of the battery. The conventional symbol universally employed to denote a battery consists of a long thin stroke to represent the positive pole of a cell and a short thick line or a short outlined oblong to represent the negative pole. Three cells, illustrated in Fig. 12, are joined up in series, and it will be observed that in this case the cells all tend to send their current in the same direction. Each cell

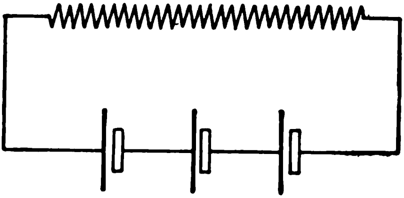

FIG. 12.—Cells in series.

therefore adds its pressure to that of the others, but, in so doing, also adds its own internal resistance. The total E.M.F. produced by a battery, consisting of a number of cells joined in series, is equal to the E.M.F. of one cell multiplied by the number of cells in series, whilst the total internal resistance is equal to the internal resistance of one cell multiplied by the number in series.

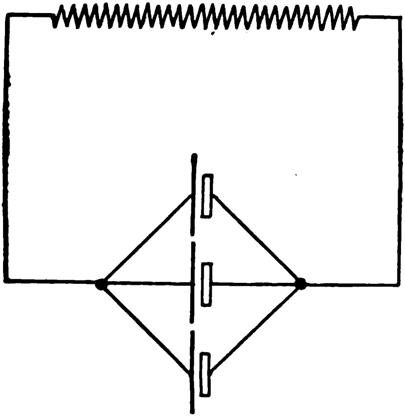

FIG. 13.—Cells in Parallel.

If the E.M.F. and internal resistance of each of the three cells shown in Fig. 12 is respectively 1 volt and 6 ohms the total E.M.F. of the battery will be 1 × 3 = 3 volts, and its internal resistance will be 6 × 3 = 18$^{\omega}$.

CELLS IN PARALLEL.

The parallel method consists in joining all the positive poles together and similarly connecting all the negative poles. The circuit to be energized is then joined between the grouped positive and negative poles of the cells. In this case the pressures are not cumulative as in the series method. The total E.M.F. of the arrangement is the E.M.F. of one cell, but the total internal resistance is the internal resistance of one cell divided by the number in parallel. For instance, if the three cells shown in Fig. 13 each have an E.M.F. of one volt and an internal resistance of six ohms, the total E.M.F. and internal resistance of the arrangement will be respectively 1 volt and $\frac{6}{3}^{\omega}$, *i. e.* 2 ohms.

CELLS IN MULTIPLE ARC.

The parallel-series or multiple-arc method of joining up cells consists in putting in parallel two or more batteries, each consisting of an equal number of cells joined in series. In Fig. 14 six cells have been connected up in multiple arc. The arrangement obviously consists of two batteries, each of three cells in series, connected in parallel. Using the same values as before for the E.M.F. and internal resistance per cell, it will be seen that the total E.M.F. and total internal resistance of either of the three-cell batteries separately considered will be as before (Fig. 12), 3 volts and 18^{ω} respectively. The question now becomes—what will be the effect of putting two such batteries in parallel? The rule given for cells in parallel may be applied to batteries in parallel, and the answer is therefore:—

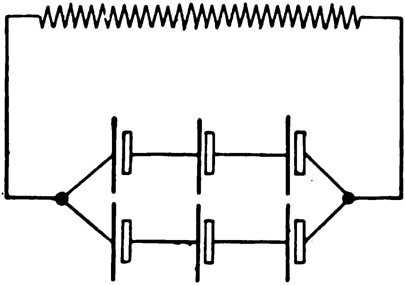

FIG. 14.—Cells in multiple arc.

Total E.M.F. = that of one battery, viz. 3 volts.

Total Internal resistance = that of one battery divided by the number of similar batteries in parallel, *i.e.*

$$\frac{18^{\omega}}{2} = 9^{\omega}.$$

In all examples of the parallel-series type the total E.M.F. is equal to the E.M.F. per cell multiplied by the number in series, and the total internal resistance is equal to the internal resistance per cell multiplied by the number of cells in series and divided by the number of similar sets or rows in parallel. Had there been six rows in the above example then the E.M.F. would have been 3 volts as before, but the internal resistance would have been reduced to 3^{ω}.

In practical telegraphy there are but few cases where it is necessary to join batteries in parallel, and the term battery is usually employed to denote cells in series. For instance a "5-cell Daniell" means five cells joined up in series, and "two 5-cell Daniells in parallel" would therefore mean two batteries, consisting of five cells in series each, connected in parallel, *i. e.* 2 rows in parallel, each row consisting of five cells in series.

METHOD IN WHICH TO JOIN UP CELLS IN DIFFERENT CIRCUMSTANCES.[*]

The three methods of joining up cells each have their particular utility, and although the parallel method is never, and the parallel series method but seldom, used in practical telegraphy, it is still desirable to state briefly the conditions under which each arrangement should be employed.

The maximum current which can be obtained from any particular cell is reached when the cell is short-circuited and is equal to its E.M.F. divided by its internal resistance. Similarly if a thousand cells be placed in series and short-circuited the maximum current will be the same, for whilst the E.M.F. has been increased a thousand-fold the internal resistance has been similarly increased.

If it is required to obtain a larger current from the cells they must be placed in parallel. Every cell which is added increases the current, for although the E.M.F. remains the same, the internal resistance is reduced by every fresh cell. If, now, the current produced by a number of cells joined up in series and flowing through a circuit of enormously high resistance is considered it will at once be seen that the internal resistance of the cells is insignificant in comparison with the enormous external resistance. Each cell added in series will therefore increase the current flowing in the circuit. Upon the other hand, the only effect of joining cells in parallel is to reduce the total internal resistance, and this is of no consequence in comparison with the external resistance. The E.M.F. remains the same, and consequently the addition of cells in parallel means no practical increase in the current available.

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[*] This subject is dealt with exhaustively in Dunton's *Treatise on the grouping of Electric Cells* (Spon).

It will now be clear that, for external resistances large in comparison with that of the cell, the cells should be joined in series, whilst for a low resistance the cells should be joined in parallel, *i. e.* in order to obtain the maximum current from the minimum number of cells.

Between the extremes already discussed come the cases where parallel series arrangements are necessary. The rule, which may be deduced from Ohm's law, relating to this case is that the arrangement of cells which gives an internal resistance most nearly approximating to the external resistance will furnish the maximum current.* To give a numerical example:—Suppose that it is desired to know how best to join up forty cells, each having an E.M.F. of 2 volts and an internal resistance of $12{\cdot}5^{\omega}$ to a circuit having a resistance of 20^{ω}.

The forty cells may be joined up in the following ways:—(*a*) all in parallel, (*b*) all in series, (*c*) two rows in parallel each of 20 in series, (*d*) four rows in parallel each of 10 in series, (*e*) five rows in parallel each of 8 in series, (*f*) eight rows in parallel each of 5 in series.

With the arrangement (*e*) the internal resistance of the battery is the same as the external resistance, viz. 20^{ω}, and this gives the maximum current, viz. 400 m.a. The currents for each of the arrangements are (*a*) 98·5 m.a., (*b*) 153·8 m.a., (*c*) 275·8, (*d*) 390·2, (*e*) 400 m.a., (*f*) 359·6 m.a.

---

* The arrangement which produces the maximum current is that in which the internal resistance is geometrically (*not* arithmetically) nearest to the external resistance. For example, two arrangements having internal resistances of 10^{ω} and 40^{ω} respectively would produce equal currents through an external resistance of 20^{ω}, because $10^{\omega} : 20^{\omega} :: 20^{\omega} : 40^{\omega}$.

From that which has been said it follows that the maximum amount of power obtainable from any battery is greatest when the external resistance is equal to the internal resistance. When this is the case the efficiency is 50 %, because there is as much energy lost in overcoming the internal resistance of the battery as is available in the external circuit.

With a given number of cells the maximum current is obtained through a given external resistance when the number of cells in series (n) is equal to the square root of the total number of cells (N) multiplied by the external resistance (R) divided by the internal resistance per cell (r).

$$n = \sqrt{\frac{N \times R}{r}}.$$

The result obtained in the previous example may be found by application of this formula thus:—

$$\sqrt{\frac{40 \times 20}{12{\cdot}5}} = \sqrt{64} = 8 \text{ in series.}$$

The number of rows is obtained by dividing the total number of cells by the number per row, *i.e.* by the number in series.

When a fractional answer is obtained the nearest whole number which will give a whole number when divided into the total number of cells must be chosen.

Example.—How should sixty cells, having an E.M.F. of 1·5 volts and an internal resistance of 2^{ω} per cell be arranged so as to provide the maximum possible current through an external resistance of $\cdot 55^{\omega}$?

$$\sqrt{\frac{60 \times \cdot 55}{2}} = \sqrt{16{\cdot}5} = 4{\cdot}06.$$

The whole number which will divide into 60 and give a whole number as quotient are 1, 2, 3, 4, 5, 6, 10, 12, 15, 20, 30 and 60. 4·06 is nearer to 4 than to any other of these numbers, and the best arrangement is therefore fifteen rows each of four cells in series.

CELLS WRONGLY JOINED UP AND SPECIAL ARRANGEMENTS.

In each of the foregoing cases the cells have been correctly joined up. It will now be well to consider one or two simple cases of wrong connection. If, in joining a number of cells in series, some of the cells are reversed, the total E.M.F. will be reduced whilst the total internal resistance will be unaffected. The E.M.F. will be equal to the E.M.F. of the larger number acting in one direction, less the E.M.F. of the smaller number acting in the opposite direction. Where the numbers are equal the E.M.F.s will balance and no current will result; that is, of course, supposing that the E.M.F.s per cell are equal.

Example.—Ten cells joined in series, E.M.F. 1 volt and internal resistance 5^{ω} per cell, are connected to a resistance of 50^{ω}. What current will be produced if two of the cells are reversed?

E.M.F. of larger number of cells = 8^{v}
„ of lesser „ „ = 2^{v}
Total E.M.F. of combination = 6^{v}

$$\text{Current} = \frac{6^{v}}{50 + 50} = \cdot 06 \text{ ampere.}$$

In certain cases a combination of parallel and series methods of joining up might be adopted, as, for instance, where a number of small cells are used in conjunction with a number of cells of larger size.

Example.—What will be the total E.M.F. and internal resistance produced by joining two 5-cell Large Daniells in series with two 10-cell Small Daniell batteries placed in parallel? E.M.F. 1 volt per cell. Internal resistance Large 5^{ω} Small 10^{ω} per cell.

Total E.M.F. of two 10-cell Small Daniells in parallel = 10^{v}
„ „ of two 5-cell Large Daniells in series = 10^{v}
Total E.M.F. of above in series = 20^{v}

Internal resistance of Large Daniells = $5^{\omega} \times 10 = 50^{\omega}$

„ „ Small Daniells = $\dfrac{10^{\omega} \times 10}{2} = 50^{\omega}$

Total internal resistance of above in series = 100^{ω}.

In other words this combination is equivalent to four 5-cell Large Daniell batteries joined in series.

In the above case the batteries placed in parallel had the same E.M.F. Where this is not the case, the battery of higher E.M.F. drives a current through the battery of lower E.M.F. Such an arrangement is most inefficient and is never intentionally used in practice, although it occasionally occurs by accident.

A simple rule for calculating the current due to such an arrangement is that the two batteries are equivalent, as regards the external circuit, to a new battery whose E.M.F. equals the E.M.F. of one of them multiplied by the resistance of the other plus the E.M.F. of the latter multiplied by the resistance of the former, the sum being divided by the sum of their internal resistances, whilst the internal resistance of this new battery is equal to the joint resistance of the two batteries.*

NUMBER OF CELLS REQUIRED TO FURNISH A GIVEN CURRENT.

It is frequently necessary to find the number of cells which will be required to furnish a given current through a certain external resistance. If the internal resistance of the cells required is negligible—as in the case of secondary cells—the required number of cells is obtained by ascertaining the voltage necessary and then dividing it by the E.M.F. per cell.

---

* The value of the current C in the external circuit is also given by the following equation :—

$$C = \frac{e_1 r_2 + e_2 r_1}{r_1 r_2 + r_1 r_3 + r_2 r_3}$$

where
e_1 = E.M.F. of first cell.
e_2 = ,, second cell.
r_1 = Internal resistance of first cell.
r_2 = ,, ,, second cell.
r_3 = External resistance.

If the two cells are joined up so that the cells combine together in series the numerator of the equation should be altered to $e_1 r_2 - e_2 r_1$. From this, it follows that when no current flows through the external circuit the ratio of the E.M.F.s of the two cells is equal to the ratio of their internal resistances.

Example.—How many secondary cells will be required to furnish a current of 20 m.a. through a circuit of 1536_{ω}?

Note.—E.M F. per cell should be taken as 2 volts.

$$\text{Current} \times \text{resistance} = \text{E.M.F. required}$$
$$\cdot 02 \times 1536 = 30\cdot 72 \text{ volts.}$$
$$\frac{\text{Total E.M.F.}}{\text{E.M.F. per cell}} = \text{Number of cells}$$
$$\frac{30\cdot 72}{2} = 15\cdot 36, \textit{ i. e. } 16 \text{ cells.}$$

The answer 15·36 is not practical because a special cell having an E M.F. of ·36 of the E.M.F. of 2 volts would have to be designed, and therefore the smallest whole number in excess of the result is taken.

In the case of primary cells the internal resistance cannot usually be ignored and the procedure shown above cannot be followed, because the total resistance of the circuit is not known until the number of cells in circuit is ascertained. The calculation of the current through a circuit connected to a battery consisting of a number of cells in series has been shown on page 40. By the aid of a little elementary algebra the following rule can be readily obtained:*—

$$\text{Number of cells} = \frac{\text{External resistance}}{\dfrac{\text{E.M.F. per cell}}{\text{Current required}} - \text{Internal res. per cell}},$$

i. e. divide the E.M.F. per cell by the current required (in amperes), and from this deduct the internal resistance per cell. The number of cells required is then equal to the external resistance divided by the result of the first operation.

Example.—How many cells E.M.F. 1^{v} per cell and internal resistance 10^{ω} per cell will be required to provide a current of 15 m.a. through a resistance of 1200_{ω}?

$$\frac{1200}{\dfrac{1}{\cdot 015} - 10} = 21\cdot 18, \textit{ i. e. } 22 \text{ cells.}$$

---

* $\frac{ne}{nr + R} = C \therefore n = \frac{R}{\frac{e}{C} - r}$ where n = number of cells in series, r = internal res. per cell, R = external res., and C = current in amperes.

The result obtained from wrongly using the simplified formula applicable to cases where the internal resistance is negligible would have been 18 cells. The same remarks apply to the fractional result as before, save that in this case the internal resistance of the special cell would also have to be proportionally less. The current produced by 22 cells will be slightly in excess of 15 m.a., whilst that supplied by 21 cells would be very slightly less than the specified value.

A minimum value for the E.M.F. and a maximum value for the internal resistance of each type of cell was given in Chapter I. A cell having these values is not considered to be faulty, and although the average values given by an efficiently maintained battery would be far better than these, it is clearly necessary to recognize that the worst values may obtain. In order that the specified current shall always be produced upon a telegraph circuit, the minimum value of the E.M.F. per cell and the maximum value of the internal resistance per cell are always taken in working out the battery power.

Example.—What power will be required to work a double current set through a line 100 miles of 100-lb. copper line?

Resistance of wire = 878^{ω}
„ „ the two earths = 20^{ω}
„ „ two galvanometers = 60^{ω}
„ „ one relay = 200^{ω}

Total external resistance = 1158^{ω}

Leclanché No. 1 cells, E.M.F. 1^{v}, internal resistance 2^{ω} per cell, are employed. 14 m.a. required.

$$\text{Number of cells required} = \frac{1158}{\dfrac{1}{\cdot 014} - 2} = 16{\cdot}7$$

or 17 cells.

SPECIAL CASES.

The internal resistance of the battery employed upon telegraph circuits is nearly always much less than that of the external circuit, and therefore the cells are generally arranged in simple series. In such cases the formula just given is always applicable, and the result obtained may be accepted without question. Where, however, the internal resistance approaches or approximates to that of the external circuit a certain amount of caution is necessary. This condition is fortunately indicated by the formula. If the E.M.F. per cell divided by the current is not at least twice the value of the internal resistance per cell, then a multiple-series arrangement is necessary. If the internal resistance is greater than the first-named quantity, the current cannot be provided by cells in simple series. The maximum current is obtained from a cell when it is short-circuited, and this current is the same as that obtained from, say, a thousand cells placed in series and short-circuited.

The internal resistance of a number of cells in multiple arc is:—

$$\frac{\text{Internal resistance per cell}}{\text{Number of rows}} \times \text{Number in series.}$$

(This is identically the same as the statement on page 39.)

A battery consisting of two rows of cells in parallel is equivalent to one battery (in simple series), having the same number of cells as one row of the former, but having an internal resistance equal to half that of the former per cell.

This forms the key to the solution of such a problem as the following:—

Example.—How many cells having an E.M.F. of two volts and an internal resistance of 10^{ω} per cell will be required to furnish a current of 400 m.a. through an external resistance of 18^{ω}?

Simple series:—

$$\frac{18}{\frac{2}{\cdot 4} - 10} = \frac{18}{5 - 10}.$$

Denominator negative, therefore simple series will not meet the case.

Two rows :—

$$\frac{18}{5-5} = \text{Infinity.}$$

Three rows :—

$$\frac{18}{5-3\frac{1}{3}} = 10{\cdot}8, \text{ i.e. } 11 \text{ cells.}$$

Note.—E.M.F. ÷ current is *less* than twice the internal resistance.

Four rows :—

$$\frac{18}{5-2\frac{1}{2}} = 7{\cdot}2, \text{ i.e. } 8 \text{ cells.}$$

Five rows :—

$$\frac{18}{5-2} = 6 \text{ cells.}$$

Six rows :—

$$\frac{18}{5-1\frac{2}{3}} = 5{\cdot}4, \text{ i.e. } 6 \text{ cells.}$$

The total number of cells required is as follows :—

Three rows	33
Four rows	32
Five rows	30
Six rows	36

The arrangement with five rows gives the smallest number of cells, and is therefore to be preferred. Where two different arrangements give the same result it is well to remember that the resistance of a primary battery will rise towards the end of its discharge, and therefore the arrangement with the lower value of internal resistance should be chosen. It may also be noted that the larger the number of rows the smaller is the current provided by each cell.

PART II.—JOINT RESISTANCE AND DIVISION OF CURRENT.

The total resistance offered by circuits or conductors placed in series is equal to the sum of their separate resistances. For instance, the total resistance of the conductors depicted in Fig. 15 is 1623^{ω}.

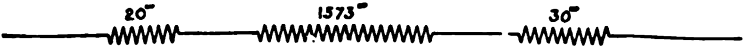

FIG. 15.—Resistances in series.

Before dealing with resistances in parallel it is necessary to define some of the important terms which are commonly employed.

Conductance has exactly the opposite meaning to resistance, and may be defined as the inverse of resistance. From this definition it follows that

$$\text{Conductance} = \frac{1}{\text{Resistance}}$$

$$\text{and Resistance} = \frac{1}{\text{Conductance}}.$$

The unit of resistance is the "ohm," and that of conductance is the "mho," which is "ohm" written backwards. A circuit having a resistance of one ohm has a conductance of one mho, so that the two units themselves have the same numerical value in this case. A circuit having a resistance of 10^{ω} has a conductance of $\frac{1}{10}$ mho, whilst a circuit having a resistance of $\frac{1}{10}^{\omega}$ would have a conductance of 10 mhos.

This definition of conductance is extremely useful in making clear the methods of finding the resistance of a number of paths in parallel and the proportion in which a given value of current will divide amongst them.

It has been found that *the total conductance of a number of paths in parallel is equal to the sum of their separate conductances.* The joint resistance or total resistance offered by the combination of paths is therefore the reciprocal of their total conductance, which latter is obtained by adding together the conductance of each path.

An example of the application of these rules is appended:

What is the joint resistance of four paths having resistances of respectively 2^{ω}, 3^{ω}, 4^{ω}, and 5^{ω} placed in parallel?

Total conductance = sum of separate conductances
„ „ $= \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \frac{1}{5}$ mho.

Resistance $= \dfrac{1}{\text{Conductance}}$

Joint resistance $= \dfrac{1}{\text{Total conductance}}$

$$= \frac{1}{\frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \frac{1}{5}} \text{ ohm}$$

$$= \frac{1}{\frac{77}{60}} = \frac{60}{77} \text{ ohm.}$$

In the case of a number of paths of equal resistance placed in parallel inspection of the previous example will at once reveal the fact that their joint resistance is equal to the resistance of one of them divided by the number of paths in parallel. For instance the joint resistance of ten 1000^{ω} paths placed in parallel is $\frac{1000}{10} = 100^{\omega}$.

Another very useful rule may, with the aid of a little simple algebra, be deduced from the rule on p. 48. It is that *the resistance of two paths in parallel is equal to their product divided by their sum.* An example of its application is given below:—

What is the joint resistance of a 50^{ω} path in parallel with a 150^{ω} path?

$$\text{Joint res.} = \frac{\text{Product}}{\text{Sum}} = \frac{50 \times 150}{50 + 150} = \frac{7500}{200} = 37{\cdot}5^{\omega}.$$

A formula may be deduced for three, four, five, or any number of paths.*

A problem which occasionally crops up in practice is

---

* The joint resistance of n paths a^{ω}, b^{ω}, c^{ω}, d^{ω} . . . in parallel

$$= \frac{a \times b \times c \times d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (n-1) \times n}{\frac{S}{a} + \frac{S}{b} + \frac{S}{c} + \frac{S}{d} \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \frac{S}{n-1} \times \frac{S}{n}}$$

where S is the product of the resistances of the n paths and forms the numerator of the formula.

that in which the joint resistance and the resistance of one of the two paths in parallel only are known. From this information the resistance of the other path may readily be obtained.

It has already been stated that the total conductance is equal to the sum of the separate conductances. In the case of two circuits in parallel the total conductance is equal to the conductance of the two added together. Hence the conductance of one of the circuits is clearly equal to the total conductance, less the conductance of the other circuit.

An example is appended:—The joint resistance of two paths in parallel is 20^{ω}, and the resistance of one of them is known to be 30^{ω}. Find the resistance of the other path.

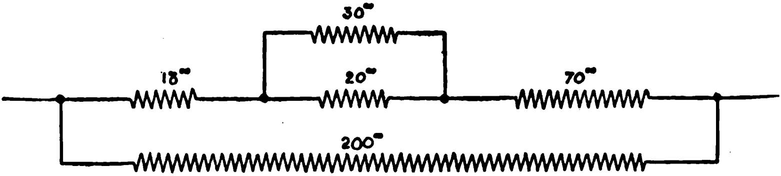

FIG. 16.—Resistances combined in series and parallel.

Conductance of first circuit = total conductance − conductance of second circuit.

$$\text{Conductance of first circuit} = \frac{1}{20} - \frac{1}{30} \text{ mho}$$

$$\therefore \text{Resistance of first circuit} = \frac{1}{\frac{1}{20} - \frac{1}{30}} \text{ ohms}$$

$$= 60^{\omega}.$$

An example of a somewhat complicated circuit is shown in Fig. 16. The total resistance of the arrangement is equal to the joint resistance of 200^{ω} and the resistance of the remainder of the circuit. The example would be worked as follows:—

$$\text{Joint resistance of } 20^{\omega} \text{ and } 30^{\omega} \text{ paths} = \frac{20 \times 30}{20 + 30} = 12^{\omega}$$

$$\text{Total resistance of upper path} = 18 + 12 + 70 = 100^{\omega}$$

$$\text{Resistance of whole combination} = \frac{100 \times 200}{100 + 200}$$

$$= 66\tfrac{2}{3}^{\omega}.$$

From the extensions of Ohm's law known as Kirchhoff's laws it can readily be shown that *a current divides between a number of paths in parallel in direct proportion to their respective conductances.* An example of the application of this rule is given below:—

A current of 10 amperes divides between four paths in parallel whose resistances are respectively 3^{ω}, 4^{ω}, 5^{ω}, and 6^{ω}. What is the value of the current in each path?

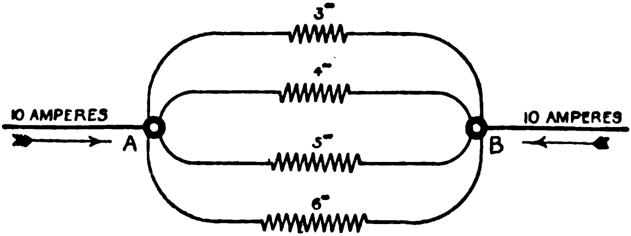

Fig. 17.—Division of current between paths in parallel.

The conditions of the problem are shown in Fig. 17.

Resistances of paths	3^{ω}	4^{ω}	5^{ω}	6^{ω}
Conductances of paths	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{5}$	$\frac{1}{6}$
The 10 amperes divide as	$\frac{1}{3}$:	$\frac{1}{4}$:	$\frac{1}{5}$:	$\frac{1}{6}$
Bringing to common denominator	$\frac{20}{60}$:	$\frac{15}{60}$:	$\frac{12}{60}$:	$\frac{10}{60}$
The 10 amperes divide as	20 :	15 :	12 :	10

$\therefore$ if the total current splits into $20 + 15 + 12 + 10 = 57$ parts,

the current through each path is respectively $\frac{20}{57}$, $\frac{15}{57}$, $\frac{12}{57}$, $\frac{10}{57}$ of 10 amperes.

i. e. $3\frac{29}{57}$, $2\frac{36}{57}$, $2\frac{6}{57}$, $1\frac{43}{57}$ amperes.

Obviously if this result is correct the sum of the currents should be 10 amperes, and by trial it will be found to be so. The current in the 6^{ω} path should be half that in the 3^{ω} path. These points enable one rapidly to test the accuracy of the arithmetic involved.

A useful rule, the accuracy of which may readily be checked by the above methods, is that by which the current through two paths A and B in parallel may be at once written down without calculation. The current through A is $\frac{B}{A+B}$ of the total current, and that through B is $\frac{A}{A+B}$ of the total current, *e.g.*

A current of 10 amperes divides between two paths of 2^{ω} and 3^{ω} placed in parallel. What is the current in each?

$$\text{In the } 2^{\omega} \text{ path } \frac{3}{2+3} \text{ of 10 amps} = 6 \text{ amperes.}$$

$$\text{In the } 3^{\omega} \text{ path } \frac{2}{2+3} \text{ of 10 amps} = 4 \text{ amperes.}$$

It is sometimes necessary to deduce the resistance of a path of unknown resistance, placed in parallel with another of known resistance, from a knowledge of the proportion in which a current divides between them. It has been previously pointed out that the current splits in direct proportion to the conductances of the paths. The converse of this is obviously true, viz. that the conductances of paths in parallel are proportional to the currents in each. An example is given below:—

The currents in two paths in parallel are respectively 10 amperes and 8 amperes. If the resistance of the higher path is 40^{ω}, what is the resistance of the other?

Currents in the paths respectively 10 and 8 amperes
∴ Conductances of the paths 10 : 8

$$\text{The conductance of the better path} = \frac{10}{8} \text{ of the other.}$$

$$\text{Conductance of other path} = \frac{1}{40}$$

$$\therefore \text{ Conductance of better path} = \frac{10}{8} \text{ of } \frac{1}{40}$$

$$= \frac{1}{32} \text{ mho}$$

$$\text{Resistance of better path} = 32^{\omega}.$$

Another method of working this problem is given in order to clearly demonstrate a useful fact in connection with circuits in parallel. Referring again to Fig. 17; the difference of potential between *A* and *B* can have but one value, since were this not the case either the point *A* or the point *B* would have two different potentials at one time. This is clearly impossible, hence the current in each path multiplied by its resistance gives the difference of potential between its ends, and this is the same for all the paths. Practically, this statement means that Ohm's law may be applied to a part of a circuit. Had there been batteries inserted in the paths the question would have been a little more complicated.

The working of the previous example by means of the facts stated above is appended.

Resistance of highest path 40^ω
Current in „ „ 8 amperes.

Difference of potential between its ends $40 \times 8 = 320$ volts.

$$R = \frac{E}{C} \therefore \text{ Resistance of other path } \frac{320}{10} = 32^\omega.$$

The current sent through any circuit by a battery is equal to its E.M.F. divided by the total resistance of the circuit. This total resistance is made up of the internal resistance of the battery and the external resistance. For instance, a battery having an E.M.F. of 20^v and an internal resistance of 100^ω applied to a circuit of 400^ω will produce a current of $\frac{20}{100 + 400}$ or 40 m.a. Where two or more paths are joined in parallel to a battery the external resistance is equal to their joint resistance, as in the following example:—

Example.—What current will be produced in each of four circuits of respectively 20^ω, 30^ω, 100^ω and 150^ω resistance joined in parallel to three five-cell Large Daniell batteries also joined in parallel? E.M.F. per cell one volt. Internal resistance 6^ω per cell.

E.M.F. of battery $= 1^{v} \times 5 = 5$ volts.

Internal resistance $= \dfrac{6 \times 5}{3} = 10^{\omega}$

Resistances of paths $20^{\omega}\ 30^{\omega}\ 100^{\omega}\ 150^{\omega}$

Conductances of paths $\frac{1}{20}\ \frac{1}{30}\ \frac{1}{100}\ \frac{1}{150}$

Bringing to common denominator $\dfrac{15}{300}\ \dfrac{10}{300}\ \dfrac{3}{300}\ \dfrac{2}{300}$

Total conductance $= \dfrac{15 + 10 + 3 + 2}{300} = \dfrac{30}{300}$

Joint resistance $= \dfrac{300}{30} = 10^{\omega}$

Total current $= \dfrac{5}{10 + 10} = \dfrac{5}{20} = 250$ m.a.

The current splits as $15 : 10 : 3 : 2$

$\therefore$ if 250 m.a. splits into $15 + 10 + 3 + 2 = 30$ parts the current through each path is respectively $\dfrac{15}{30}, \dfrac{10}{30}, \dfrac{3}{30}, \dfrac{2}{30}$, of 250 m.a.

i. e. 125 m.a., 83·3 m.a., 25 m.a., 16·7 m.a.

Whilst dealing with batteries and circuits it will perhaps be well to deduce the relations which exist between the E.M.F. of a battery and the difference of potential between its terminals when connected to a completed circuit. This may best be done by considering a definite case. A battery having an E.M.F. of 2 volts and an internal resistance of 12^{ω} is connected to a circuit having a resistance of 8^{ω} (Fig. 18). The current through the circuit is $\dfrac{2}{12 + 8} = {\cdot}1$ ampere The difference of potential between the ends of the external resistance is, by Ohm's law, $\cdot 1 \times 8^{\omega} = {\cdot}8$ volt. This is a difference of potential observable at the terminals of the cell when the circuit is closed. The difference between this value and that of the E.M.F. of the battery on open circuit is the E.M.F. which is lost in traversing the resistance of the battery. The current inside the battery is obviously the same as that in the external circuit, viz. ·1 ampere. Hence the value of the E.M.F.

taken up in the battery itself is $\cdot 1 \times 12^{\omega} = 1\cdot 2$ volts, which is the value deduced from the difference between the E.M.F. on open and closed circuit. In any case of this character the whole of the E.M.F. of the cell must be accounted for.

From a knowledge of the E.M.F. of a battery upon open circuit and the differences of potential across its terminal when connected by a known resistance, the value of its internal resistance can readily be calculated. This is the principle employed in one method of measuring internal resistance. A numerical example is appended :—

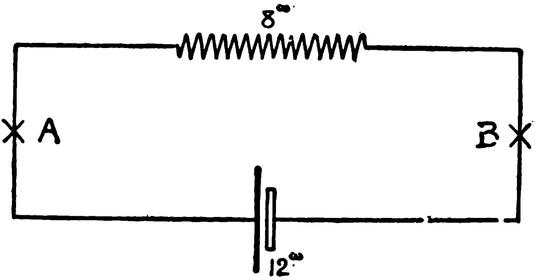

Fig. 18.—If the E.M.F. of the cell is 2^{v} the difference of potential between *A* and *B* is $\cdot 8^{v}$.

Example.—The E.M.F. of a battery upon open circuit is 30 volts, but when the circuit is closed through an external resistance of 70^{ω} the difference of potential falls to 23 volts. What is its internal resistance?

Method I.

E.M.F. of battery $= 30^{v}$
P.D. across 70^{ω} $= 23^{v}$
E.M.F. lost in battery itself $= 30 - 23 = 7^{v}$
Current in battery and in 70^{ω} circuit is the same.
∴ By Ohm's law 23 : 7 : : 70 : Internal res.

$$\text{Internal res.} = \frac{7}{23} \times 70$$

$$21\cdot 3^{\omega} = \text{approx.}$$

Method II.

E.M.F. of battery $= 30^{v}$
P.D. across 70^{ω} $= 23^{v}$
E.M.F. lost in battery itself $= 30 - 23 = 7^{v}$

$$\text{Current through } 70^{\omega} = \frac{PD}{70} = \frac{23}{70} \text{ ampere}$$

$$\text{Internal resistance of battery} = \frac{\text{E.M.F. lost}}{\text{Current}} = \frac{7}{\frac{23}{70}}$$

$$= 21{\cdot}3^{\omega} \text{ approx.}$$

PART III.—THE RESISTANCE OF WIRES OF VARYING DIMENSIONS.

It has been found by experiment that the resistance which any conductor offers to an electric current depends upon three factors, viz. :—

1. Its dimensions.
2. Its composition.
3. Its temperature.

If the resistance of any material of known dimensions has a certain value at a particular temperature, then it is a matter of ease to deduce the value of the resistance which will be offered by that material when given different dimensions at the same temperature. The changes produced by altering the temperature have been carefully determined for all the substances in common use for electrical purposes. It will therefore be seen that if the resistance of any substance of known dimensions is stated for any given temperature the determination of its resistance when made into any particular form is merely a matter of arithmetic.

Experiment proves that *the resistance of a conductor of uniform gauge is directly proportional to its length and inversely proportional to its sectional area.* It is, of course, assumed that the temperature and composition do not vary. This condition will apply to all the problems given unless otherwise specified.

In order to shorten and simplify the various proportions stated the following letters will be employed to denote the values of the resistances and dimensions stated opposite them—

l_1 to represent the length of the first wire.
l_2 „ „ „ „ second wire.
a_1 „ „ sectional area of the first wire.
a_2 „ „ „ „ „ second wire.
d_1 „ „ diameter „ „ first wire.
d_2 „ „ „ „ „ second wire.
w_1 „ „ total weight „ first wire.
w_2 „ „ „ „ „ second wire.
R_1 „ „ resistance „ first wire.
R_2 „ „ „ „ second wire.

Example 1.—If the resistance of 10 miles of wire is 89^{ω}, what is the resistance of 7 miles of similar wire?

$$\begin{array}{lccccccc} & l_1 & : & l_2 & :: & R_1 & : & R_2 \\ \textit{i.e.} & 10 & : & 7 & :: & 89 & : & R_2 \end{array}$$

$$\therefore R_2 = \frac{7 \times 89}{10} = 62{\cdot}3^{\omega}.$$

Example 2.—Two wires of similar gauge and material offer resistances of 40^{ω} and 28^{ω}. If the former is 360 yards long, what is the length of the second wire?

$$\begin{array}{lccccccc} & R_1 & : & R_2 & :: & l_1 & : & l_2 \\ \textit{i.e.} & 40 & : & 28 & :: & 360 & : & l_2 \end{array}$$

$$\therefore l_2 = \frac{28 \times 360}{40} = 252 \text{ yards.}$$

Example 3.—Two wires of equal length have sectional areas of ·12 square inch and ·15 square inch respectively. If the resistance of the smaller wire is 10^{ω}, what is the resistance of the larger?

$$\begin{array}{lccccccc} & a_2 & : & a_1 & :: & R_1 & : & R_2 \\ \textit{i.e.} & {\cdot}15 & : & {\cdot}12 & :: & 10 & : & R_2 \end{array}$$

$$\therefore R_2 = \frac{{\cdot}12 \times 10}{{\cdot}15} = 8^{\omega}.$$

Given both resistances and the area of one wire the area of the second would be found in similar fashion.

Example 4.—A wire 12 miles long having a sectional area of ·021 square inch has a resistance of 7·5 ohms. What will be the resistance of a similar wire 18 miles long having a sectional area of ·023 square inch?

$$l_1 : l_2 :: R_1 : R_2$$

also

$$a_2 : a_1 :: R_1 : R_2$$

$$\therefore \quad l_1 \times a_2 : l_2 \times a_1 :: R_1 : R_2$$

$$i.e. \quad 12 \times {\cdot}023 : 18 \times {\cdot}021 :: 7{\cdot}5 : R_2$$

$$\therefore \mathrm{R}_2 = \frac{18 \times {\cdot}021 \times 7{\cdot}5}{12 \times {\cdot}023} = 10{\cdot}27^{\omega}.$$

The sectional area of a round wire is equal to the square of its diameter multiplied by ·7854, hence it will be obvious that *the resistance of a conductor of uniform gauge is proportional to its length and inversely proportional to the square of its diameter.*

Examples of the application of this rule are appended.

Example 5.—What will be the resistance of a wire 26 yards long having a diameter of 33 mils if the resistance of a wire of the same material 52 miles long with a diameter of ·01 inch has a resistance of 32^{ω}?

Note.—In comparing either two lengths or two diameters the units of each dimension chosen should be the same, but it is not necessary that all four quantities should be in the same unit. A mil is one-thousandth of one inch.

$${\cdot}01 \text{ inch} = 10 \text{ mils.}$$

$$l_2 : l_1 :: R_2 : R_1$$

and

$$(d_1)^2 : (d_2)^2 :: R_2 : R_1$$

$$\therefore l_2 \times (d_1)^2 : l_1 \times (d_2)^2 :: R_2 : R_1$$

$$(52 \times 1760) \times 33^2 : 26 \times 10^2 :: 32 : R_1$$

$$\therefore \mathrm{R}_1 = \frac{26 \times 10^2 \times 32}{52 \times 1760 \times 33^2}$$

$$= {\cdot}0008348 \quad \text{or } 834{\cdot}8 \text{ microhms.}$$

In problems where the lengths of the two wires are equal the proportion reduces to:—

$$(d_2)^2 : (d_1)^2 :: R_1 : R_2.$$

Example 6.—A wire 30 miles long, 40 mils in diameter has a resistance of 1000^{ω}. What is the length of a wire of the same material having a resistance of 200^{ω} and a diameter of 25 mils?

$$\begin{array}{lcccccccc} & R_1 & : & R_2 & :: & l_1 \times (d_2)^2 & : & l_2 \times (d_1)^2 \\ i.e. & 1000 & : & 200 & :: & 30 \times 25^2 & : & l_2 \times 40^2 \end{array}$$

$$\therefore l_2 \times 40^2 = \frac{200 \times 30 \times 25^2}{1000}$$

$$l_2 = \frac{200 \times 30 \times 25^2}{1000 \times 40^2}$$

$$= 2{\cdot}344 \text{ miles approx.}$$

Example 7.—The resistance of an iron wire 20 miles long, having a diameter of 171 mils is $266{\cdot}4^{\omega}$. What is the diameter of a wire 3 miles long having a resistance of $79{\cdot}92^{\omega}$?

$$\begin{array}{lcccccccc} & R_2 & : & R_1 & :: & l_2 \times (d_1)^2 & : & l_1 \times (d_2)^2 \\ i.e. & 79{\cdot}92 & : & 266{\cdot}4 & :: & 3 \times 171^2 & : & 20 \times (d_2)^2 \end{array}$$

$$\therefore 20 \times (d_2)^2 = \frac{266{\cdot}4 \times 3 \times 171^2}{79{\cdot}92}$$

$$(d_2)^2 = \frac{266{\cdot}4 \times 3 \times 171^2}{79{\cdot}92 \times 20}$$

$$\therefore \quad d_2 = \sqrt{14620} = 121 \text{ mils approx.}$$

Example 8.—What is the diameter of a wire 7 miles long having the same resistance as a wire 20 miles long which has a diameter of 60 mils?

$$\begin{array}{lcccccccc} & l_1 & : & l_2 & :: & R_1 & : & R_2 \\ \text{and} & (d_2)^2 & : & (d_1)^2 & :: & R_1 & : & R_2 \\ & \therefore l_1 \times (d_2)^2 & : & l_2 \times (d_1)^2 & :: & R_1 & : & R_2 \end{array}$$

$$\text{Since} \quad R_1 = R_2$$

$$\text{then} \quad l_1 \times (d_2)^2 = l_2 \times (d_1)^2$$

$$i.e. \quad 7 \times 60^2 = 20 \times (d_1)^2$$

$$\therefore (d_1)^2 = \frac{7 \times 60^2}{20}$$

$$\text{and} \quad d_1 = \sqrt{\frac{7 \times 60^2}{20}} = 35{\cdot}5 \text{ mils approx.}$$

Where the diameter of one wire and the sectional area of another is given it is obviously necessary to reduce both to the same dimension. It has been previously stated that the area of a circle is equal to ·7854 times the square of its diameter. An example in which these complications arise is given below:—

Example 9.—A wire 17 miles long, diameter 171 mils has a resistance of 230$^{\omega}$. What is the resistance of a similar wire 152 yards long having a sectional area of ·02 square inch?

Note.—As in the previous problem both lengths must be in the same units. A similar remark also applies to the diameters.

Preliminary calculations.

The area of a circle $= \frac{\pi}{4} \times (\text{diameter})^2$.

$$\pi = 3{\cdot}1416 \; \therefore \frac{\pi}{4} = {\cdot}7854.$$

Diameter of wire = 171 mils = ·171 inch.

Area of wire ·171 inch in diameter $= {\cdot}7854 \times {\cdot}171^2$ = ·023 square inch.

As in example 4.

$$l_1 \times a_2 \;:\; l_2 \times a_1 \;::\; R_1 \;:\; R_2$$
$$i.e.\ 17 \times 1760 \times {\cdot}02 \;:\; 152 \times {\cdot}023 \;::\; 230 \;:\; R_2$$
$$\therefore R_2 = \frac{152 \times {\cdot}023 \times 230}{17 \times 1760 \times {\cdot}02} = 1{\cdot}34^{\omega}.$$

The rules given for the comparison of the resistances of wires of differing dimensions are merely deductions from the experimentally determined equation:—

$$R = \frac{l \times S}{a}$$

where l = length of conductor (inches or cms.).
a = sectional area of conductor (inches or cms.).
S = specific resistance or resistivity, as it is now termed (cubic inches or c. cms.).
R = resistance of conductor in ohms.

If l and a are made unity then R is equal to S, hence resistivity of any substance is the resistance between the opposite faces of a unit cube of that material. Since both inches and centimetres are in daily use as units it is necessary to specify the unit employed. The resistivity of a substance is therefore defined as so many microhms per cubic inch or per cubic centimetre, according to the unit chosen. It is scarcely necessary to remark that l, a, and S must all be in either centimetres or inches and not a compound of both.

The resistivities of a few materials, taken from the observations of Dewar and Fleming, are given below:—

Material.	**Resistivity at 0° C.**	
	Microhms per cubic inch.	**Microhms per cubic centimetre.**
Silver (electrolytic) .	·57795	1·468
Copper* ,, . .	·61457	1·561
Gold	·86496	2·197
Aluminium . .	1·049	2·665
Zinc	2·2642	5·751
Nickel (electrolytic) .	2·7303	6·935
Iron	3·5689	9·065
Tin (pressed) . .	5·137	13·048
Lead (pressed) . .	8·0236	20·38
Mercury . . .	37·04	94·07
German silver . .	8 to 12	20 to 30
Graphite . . .	118 to 157	300 to 400
Saturated solution of sulphate of copper .	$11{\cdot}535 \times 10^6$	$29{\cdot}3 \times 10^6$
Saturated solution of sulphate of zinc .	$13{\cdot}268 \times 10^6$	$33{\cdot}7 \times 10^6$

Example 10.—What is the resistance of one mile of copper wire 112 mils in diameter, given the resistivity as ·681327 microhms per cubic inch?

---

* Modern tables of copper resistance are based on the following values—

Res. of metre-gramme of hard copper at 60° F = ·1539ω

,, ,, ,, soft ,, = ·1508ω

1 cubic foot of copper weighs 555 lbs. or 8·89 grammes per cubic centimetre at 60° F. Specific gravity 8·90.

The resistance of soft copper is ·66783 microhm per cubic inch, and 1·6963 microhm per cubic centimetre, whilst the corresponding values for hard copper are respectively ·68154 and 1·73116 microhms.

The resistivity of pure iron is 10·616 microhms per cubic centimetre. One mile of pure iron wire having a resistance of one ohm weighs 4656 lbs., whilst an ohm-mile of commercial wire should not weigh more than 5328 lbs. (See page 64.)

$$R = \frac{(1760 \times 36) \times {\cdot}681327}{{\cdot}7854 \times ({\cdot}112)^2} \text{ microhms}$$
$$= 4{,}382{,}000 \text{ microhms approx.}$$
$$= 4{\cdot}382^{\omega}.$$

It may also be well to note that the statement upon page 60 may be written in the following form:—

$$\text{Specific resistance (per cubic inch or per cubic cm.)} = \frac{\text{Res. in ohms} \times \text{area (inches or cms.)}}{\text{Length (inches or cms.)}}$$

All quantities must be in *inches* or *all* in *centimetres.*

An example of the application of these facts is appended.

Example 11.—Compare the specific resistances of iron and copper, given that 1 mile of iron wire 171 mils in diameter has a resistance of 13·32 ohms, whilst a mile of copper wire having a diameter of 97 mils has a resistance of 5·855 ohms.

$$\text{Specific res. of iron per cub. in.} = \frac{13{\cdot}32 \times ({\cdot}171^2 \times {\cdot}7854)}{1760 \times 36}$$
$$= 4{\cdot}829 \text{ microhms approx.}$$

$$\text{Specific res. of copper per cub. in.} = \frac{5{\cdot}855 \times ({\cdot}097^2 \times {\cdot}7854)}{1760 \times 36}$$
$$= {\cdot}6829 \text{ microhms approx.}$$

Answer. 4·828 : ·6829
or 7·07 : 1.

This may also be expressed by the statement that the iron has a conductivity equal to 14·14% of that of the copper.

There is still another way in which the gauge of a wire may be specified, and this is by stating its weight per unit length. This method is adopted by the Department, and it will therefore be necessary to consider the relations between the length, weight and resistance of a wire.

The weight of a wire of uniform section is directly proportional to its cubic contents, *i.e.* to its length multiplied by its sectional area. It has already been stated that the resistance of a wire is directly proportional to its length divided by the square of its diameter. If both the numerator and denominator of a fraction are multiplied by the same quantity the value of the fraction is unaltered, therefore the relation may be re-stated thus:— the resistance of a wire varies directly as the square of its length, and inversely as the product of its length and its diameter squared. The latter quantity is directly proportional to its weight, hence the rule becomes:—*the resistance of a conductor of uniform gauge is directly proportional to the square of its length and inversely as its total weight.*

If two wires of the same total weight are respectively one and two yards long, then their resistances will be as one is to four. Not only is the length of wire greater in the second case, but its gauge is less since it is obvious that the same quantity of metal is spread over two yards instead of one.

An example of the application of the above rule is appended:—

Example 12.—A wire 80 yards long weighing 30 lbs. has a resistance of 2^{ω}. What will be the resistance of a similar wire 60 yards long weighing only 12 lbs.?

$$\begin{array}{lccccccc} & (l_1)^2 & : & (l_2)^2 & :: & R_1 & : & R_2 \\ \text{and} & w_2 & : & w_1 & :: & R_1 & : & R_2 \\ \therefore & (l_1)^2 \times w_2 & : & (l_2)^2 \times w_1 & :: & R_1 & : & R_2 \\ \textit{i.e.} & 80^2 \times 12 & : & 60^2 \times 30 & :: & 2 & : & R_2 \end{array}$$

$$\therefore R_2 = \frac{60^2 \times 30 \times 2}{80^2 \times 12} = 2{\cdot}8125^{\omega}.$$

When applying these rules care must be taken to express the weights of both wires as *total* weights. As will be shown later, the *weight per mile* specifies the gauge of the conductor, and its resistance is therefore proportional to the simple length.

Example 13.—A wire 1500 yards long weighing 300 lbs. per mile has a resistance of 3^{ω}. What resistance will be offered by a wire of similar material 80 yards long having a total weight of 1 cwt.?

Total weight of 1500 yards of wire weighing 300 lbs. per mile $= \frac{1500 \times 300}{1760}$.

$$(l_1)^2 : (l_2)^2 :: R_1 : R_2$$

and

$$w_2 : w_1 :: R_1 : R_2$$

$$\therefore (l_1)^2 \times w_2 : (l_2)^2 \times w_1 :: R_1 : R_2$$

$$1500^2 \times 112 : 80^2 \times \frac{1500 \times 300}{1760} :: 3 : R_2$$

$$\therefore R_2 = \frac{80^2 \times \frac{1500 \times 300}{1760} \times 3}{1500^2 \times 112} = \frac{3}{154} = \cdot 01948^{\omega}.$$

The weight of a wire of given length and material is proportional to its sectional area. It will therefore be evident that the rule given upon page 56 may also be written "*the resistance of a conductor of uniform gauge varies directly as its length and inversely as its weight per mile.*" The application of the rule is so obvious in view of examples 1 to 4 that no illustrations should be necessary.

In practice the various sizes of wire are named by their weights per mile. For instance, an iron wire weighing 400 lbs. per mile is termed a "400-lb. iron wire." As the resistance per mile of any particular kind of wire is inversely proportional to its weight per mile it will therefore seem that the two quantities when multiplied together will always give the same result. Hence by remembering this number for iron and for copper the resistance of all the various sizes of wire used by the Department may be memorized. The number is 5328 for iron and 878·73 for copper wire.

The resistance per mile of a 400-lb. iron wire is therefore $\frac{5328}{400} = 13 \cdot 32^{\omega}$, a 200-lb. iron wire similarly is $\frac{5328}{200} = 26 \cdot 64^{\omega}$, *i. e.* twice the resistance of the former.

The resistance of a 100-lb. copper wire is $\frac{878 \cdot 73}{100} = 878 \cdot 73^{\omega}$ per mile, and of a 150-lb. wire $\frac{878 \cdot 73}{150} = 5 \cdot 8582^{\omega}$ per mile.

The copper wire of commerce is not chemically pure, and the presence of impurities increases its resistance. Instead of defining the specific resistance per cubic inch, a conductivity of 99 % of that of pure copper is often specified.

From either the specific resistance per cubic centimetre or per cubic inch the resistance of any wire of that material may be calculated. In the same way, from the resistance of a foot of wire weighing one grain similar information may be deduced. This latter value is perhaps more useful in the case of conductors whose gauges are specified by their weights per mile.

The resistance of a foot-grain of pure hard-drawn copper wire is ·22064$^{\omega}$, and of pure iron 1·169$^{\omega}$ at 60° F.

The corresponding resistivity formula is :—

$$R = \frac{l^2 \times W}{w}$$

where l = length in feet
W = resistance of one foot of wire weighing one grain (7000 grains = 1 lb.)
w = total weight in grains.

Example 14.—Find the resistance of a copper wire 1 mile long weighing 100 lbs.

$$R = \frac{(1760 \times 3)^2 \times {\cdot}22064}{100 \times 7000}$$
$$= 8{\cdot}7873 \text{ ohms.}$$

There is one other class of problem which is occasionally met with. In this the weight and diameter of a wire are specified. The relation is that *the resistance varies directly as the total weight, and inversely as the fourth power of the diameter.*[*]

---

[*] w is proportional to $l \times a$

$\therefore l$ is proportional to $\frac{w}{a}$

Now R is proportional to $\frac{l}{a}$.

Substituting for l,

$$R \text{ is proportional to } \frac{\frac{w}{a}}{a} = \frac{w}{a^2}.$$

The sectional area is proportional to d^2,

$$\therefore R \text{ is proportional to } \frac{W}{d^4}.$$

Example 15.—Two wires weighing 80 lbs. and 60 lbs. have diameters respectively 100 and 40 mils. If the resistance of the thicker wire is 10^ω, what is the resistance of the other?

$$\begin{array}{rlclclclcl} & w_1 & : & w_2 & :: & R_1 & : & R_2 & & \\ & (d_2)^4 & : & (d_1)^4 & :: & R_1 & : & R_2 & & \\ \therefore & w_1 \times (d_2)^4 & : & w_2 \times (d_1)^4 & :: & R_1 & : & R_2 & & \\ \textit{i.e.} & 80 \times 40^4 & : & 60 \times 100^4 & :: & 10 & : & R_2 & & \end{array}$$

$$\therefore R_2 = \frac{60 \times 100^4 \times 10}{80 \times 40^4} = 293^\omega \text{ approx.}$$

Example 16.—Two wires having resistances of 256^ω and 81^ω weigh respectively 10 lbs. and 25 lbs. If the diameter of the first wire is 30 mils, what is the diameter of the second?

$$\begin{array}{rlclclcl} & R_2 & : & R_1 & :: & w_2 & : & w_1 \\ & R_2 & : & R_1 & :: & (d_1)^4 & : & (d_2)^4 \\ \therefore & R_2 & : & R_1 & :: & w_2 \times (d_1)^4 & : & w_1 \times (d_2)^4 \\ & 81 & : & 256 & :: & 25 \times 30^4 & : & 10 \times (d_2)^4 \end{array}$$

$$10 \times (d_2)^4 = \frac{256 \times 25 \times 30^4}{81}$$

$$(d_2)^4 = \frac{256 \times 25 \times 30^4}{81 \times 10}$$

$$d = \sqrt[4]{\frac{256 \times 25 \times 30^4}{81 \times 10}}$$

$$= 50{\cdot}3 \text{ mils approx.}$$

Application of Laws to Cells.

A consideration of the laws governing the resistance of wires of varying dimensions makes it obvious why a large cell has a lower internal resistance than a smaller one of the same type. The larger the plates the broader is the liquid between them as compared with the intervening distance. The former corresponds to the sectional area of the wire.

Effect of Temperature upon Resistance.

The temperature was assumed to be the same in all the problems dealt with, and it is therefore necessary that the effect of varying the temperature should now be considered. In the case of all metals the resistance rises as the temperature is increased. In the case of copper wire the resistance increases about ·428 per cent. per degree for each degree Centigrade, or ·238 per cent. for each degree Fahrenheit. A more accurate formula is :—

$$R_t = R_{32}\left\{1 + \cdot 0023708 \times (t - 32) + \cdot 00000034548 \times (t - 32)^2\right\}$$

where R_t = Resistance at "$t°$" F.
and R_{32} = ,, ,, 32° F.

(The numerical coefficients were determined experimentally.)

Example 17.—What is the resistance of a copper conductor at 52° F. if its resistance is 1000^{ω} at 32° F. ?

$$R_t = 1000\left\{1 + \cdot 0023708 \times 20 + \cdot 00000034548 \times 20^2\right\}$$
$$= 1047 \cdot 554192^{\omega}$$

By approximate rule (·238 % per degree F.)

$$\text{Increase} = \frac{1000}{100} \times \cdot 238 \times 20$$
$$= 47 \cdot 6^{\omega}$$
$$\therefore R_t = 1047 \cdot 6^{\omega}.$$

In the case of carbon the resistance decreases with increase of temperature, and a similar remark applies to most liquid conductors, mercury being excepted. The warming of most insulators decreases their insulating power, *i.e.* lowers their specific resistances.

The effect of changes of temperature is far more marked with insulators than with conductors, for whilst an increase of 15° F. would raise the resistance of a 1000^{ω} copper conductor to 1036^{ω}, a gutta-percha core would decrease from 9000 to 1000 megohms with the same rise in temperature. The equation connecting the resistances of insulators is of the exponential type, and varies largely with the quality as well as with the kind of material.*

In the case of gutta-percha the effect of pressure is very great. The insulation of a submerged submarine cable greatly exceeds that observed at the factory. The deeper the cable is laid the higher is its insulation resistance. This effect is due solely to the pressure exerted by the water, and amounts to 61¼% per 1000 fathoms depth. Thus a cable having an insulation of 100 megohms at atmospheric pressure would have a resistance 222½ megohms when laid at a depth of 2000 fathoms. India-rubber, on the other hand, decreases in resistance, when subjected to pressure, at the rate of about 16% per 1000 fathoms.

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* *Handbook of Electrical Testing*, by H. R. Kempe, 6th edition, p. 470.

Changes of temperature and pressure are found not to affect the true capacity of a G.P. cable. With india-rubber, a rise in temperature from 100° F. to 212° F. increased the capacity 140% (Kempe).

Experiments carried out on a screened cable (31% air, 69% paper) show that the capacity varies with the insulation of the cable, the capacity falling from ·118 mf. at 2,000 megohms, to ·108 mf. at 120,000 megohms per mile. The insulation is found to decrease from 20,000 megohms per mile at 16° C. to 2,200 megohms at 44° C., but the capacity rises with the temperature from ·1219 mf. at 15° C. to ·131 mf. at 43° C. These variations do not, however, follow any simple law.

PART IV.—ELECTROMAGNETS.*

A magnetic field is generated by a loop of wire conveying a current. The value of the field produced may be augmented by increasing the number of turns of wire.

It is now necessary also to consider the effect of introducing an iron core into the coil of wire, or solenoid, as it is termed, in this connection. Iron and steel conduct lines of force far better than does air, and a somewhat similar form of law to Ohm's law for electrical circuits applies to magnetic circuits. A magnetic circuit may be defined as the path of the magnetic lines of force. The law for a magnetic circuit is:—

$$\frac{\text{Magneto-motive force (in Gilberts)}}{\text{Reluctance (in Oersteds)}} = \text{Flux (in Maxwells)}$$

---

* Before reading this part of the chapter the reader should be familiar with the facts illustrated by Fig. 48.

The magneto-motive force corresponds to E.M.F., the reluctance or magnetic resistance to resistance and the flux or number of lines of force flowing through the magnetic circuit to the current. The reluctance of a circuit in Oersteds is equal to its length divided by the product of its sectional area and its permeability. The permeability corresponds roughly to conductivity, and may be defined as the relative conductivity of the material under consideration, and that of vacuum which is taken as unity. There is, however, a most important difference between an electric circuit and a magnetic circuit. The resistance of any particular conductor is the same for any value of current, so long as its temperature remains constant. In the case of a magnetic circuit the value varies with the magnetizing force. For instance, with a magnetizing force of 2, the permeability is 2500, whilst with 350 it has fallen to 54. The reason of these changes in value will be found in the description of the molecular theory of magnetism.

The magnetizing force of a solenoid (in Gilberts) is 1·257 times the total number of ampere-turns, *i.e.* 1·257 × current in amperes × number of convolutions. Therefore to produce any given value of magnetic flux (in Maxwells) through a given magnetic circuit, a certain number of ampere turns of wire are required. With a sounder of the pattern described later, about 200 ampere-turns are required to work the instrument satisfactorily. This may be provided by a single turn of wire upon each limb of the electromagnet, if a current of 100 amperes is provided. With one ampere 100 turns upon each limb would be needed, whilst with 100 m.a. 1000 turns per limb would be necessary.

From this fact one or two very useful rules may be deduced. One is that the maximum effect is produced by any given type of apparatus when it is wound to a resistance equal to the resistance of the rest of the circuit. The assumption which is made in this statement is that the windings occupy precisely the same space and that the wire is of the same material but of different gauge in the two instances. The relation is a trifle more complex when the thickness of the insulating covering upon the wire is taken into account, but the approximate rules which will be indicated are sufficiently near to the true results to be of considerable value.

The length of wire, and hence the number of turns of wire, which can be wound upon a bobbin of given dimensions is inversely proportional to the square of the total diameter of the wire. Thus

$$l_1 : l_2 :: (d_2)^2 : (d_1)^2$$

also
$$n_1 : n_2 :: (d_2)^2 : (d_1)^2$$

where l_1 and l_2, d_1 and d_2, n_1 and n_2 represent respectively the lengths, diameters, and number of turns of wire in each case.

But the relative resistances of the windings R_1 and R_2 in the two cases may be expressed thus:—

$$R_1 : R_2 :: l_1 \times (d_2)^2 : l_2 \times (d_1)^2.$$

Substituting for l_1 and l_2 the relative values in terms of the diameter of the wire which can be wound upon the bobbin,

$$R_1 : R_2 :: (d_2)^2 \times (d_2)^2 : (d_1)^2 \times (d_1)^2$$

$$i.e.\ R_1 : R_2 :: d_2{}^4 : d_1{}^4$$

but
$$n_1{}^2 : n_2{}^2 :: d_2{}^4 : d_1{}^4$$

$$\therefore n_1 : n_2 :: \sqrt{R_1} : \sqrt{R_2}.$$

The last relation states that the number of turns of wire wound upon an electromagnet is directly, and hence its figure of merit is inversely, proportional to the square root of the resistance of the windings.

The application of these principles may best be shown by a series of numerical examples.

Example 1.—The coils of a trembler bell (50^{ω} per coil) can be joined up in series or in parallel. Which method is preferable when the bell is directly connected to two cells in series, having an E.M.F. of 1^{v} and an internal resistance of 5^{ω} per cell?

The magnetic effects, M_1 and M_2, are proportional to the amperes turns ($A \times T$) in each case.

$$M_1 : M_2 :: A_1 \times T : A_2 \times T.$$

$$\text{In series, current} = \frac{2}{100 + 10} = \cdot 0182 \text{ amperes}$$

$$\text{In parallel, current} = \frac{2}{25 + 10} = \cdot 057 \text{ amperes.}$$

The current in each coil in the latter case is ·0285 amp. since they are in parallel.

$$\therefore M_1 : M_2 :: \cdot 0182 \times T : \cdot 0285 \times T.$$
$$\textit{i.e. } M_1 : M_2 :: \cdot 0182 : \cdot 0285.$$

Hence the coils should be placed in parallel.

Example 2.—An electromagnet is wound with two equal wires each having a resistance of 10^{ω}, and is connected to a battery having an E.M.F. of 20^{v}, and an internal resistance of 10^{ω}. Should the coils be connected in parallel or in series?

$$\text{In series, current} = \frac{20}{20 + 10} = \frac{2}{3} \text{ amp.}$$

$$\text{In parallel, current} = \frac{20}{5 + 10} = \frac{4}{3} \text{ amp.}$$

i. e. $\frac{2}{3}$ amp. in each wire.

$$\therefore M_1 : M_2 :: \tfrac{2}{3} : \tfrac{2}{3}.$$

The magnetic effects are equal in the two cases. Since the value of the current in the first case is half that in the second and the energy expended is also half as much, the series arrangement is to be preferred. Moreover, the internal resistance of the battery is likely to rise.

Example 3.—An electromagnet is wound with wire having a diameter of 20 mils to a resistance of 320^{ω}. With what diameter of wire must it be re-wound in order that its resistance may be 20^{ω}?

$$R_2 : R_1 :: d_1^4 : d_2^4.$$
$$\textit{i.e. } 20 : 320 :: 20^4 : d_2^4.$$
$$\therefore d_2^4 = \frac{320 \times 20^4}{20} \text{ mils}$$
$$d_2^2 = \sqrt{16 \times 20^4 \text{ mils}}$$
$$= 1600 \text{ mils}$$
$$d_2 = 40 \text{ mils.}$$

Example 4.—An instrument wound to a resistance of 1000^{ω} requires a current of 7 m.a. to satisfactorily work it. What current will be required to produce the same effect if it is re-wound to a resistance of 100^{ω}?

$$\begin{aligned} \sqrt{R_1} &: \sqrt{R_2} :: n_1 : n_2 \\ \sqrt{1000} &: \sqrt{100} :: n_1 : n_2 \\ \textit{i.e.}\ 31{\cdot}62 &: 10 :: n_1 : n_2 \end{aligned}$$

Since the effects are equal,

$$n_1 \times {\cdot}007 = n_2 \times C$$

$$\textit{i.e.}\ 31{\cdot}62 \times {\cdot}007 = 10 \times C$$

$$\therefore C = \frac{{\cdot}007 \times 31{\cdot}62}{10} = 22 \text{ m.a. approx.}$$

Example 5.—Two electromagnets of precisely equal dimensions are wound with the same volume of wire, but the first is wound with 14 mils wire, and the second with 4·5 mils wire. What current will be needed to produce the same effect with the second electromagnet that 200 m.a. produces with the first?

$$\begin{aligned} d_2^2 &: d_1^2 :: n_1 : n_2 \\ \textit{i.e.}\ 4{\cdot}5^2 &: 14^2 :: n_1 : n_2 \end{aligned}$$

Since the effects are equal.

$$n_1 \times {\cdot}2 = n_2 \times C$$

$$\textit{i.e.}\ 4{\cdot}5^2 \times {\cdot}2 = 14^2 \times C$$

$$\therefore C = \frac{{\cdot}2 \times 4{\cdot}5^2}{14^2} = 20{\cdot}7 \text{ m.a. approx.}$$

Example 6.—How would you join up sixty cells, each having an E.M.F. of 2 volts and an internal resistance of 4^{ω} per cell, to an electromagnet having a resistance of 15^{ω} in order to produce the largest possible effect with the means at disposal?

This is only another way of setting the type of question shown on page 39, since the effect is greatest when the current is greatest.

$$n = \sqrt{\frac{N \times R}{r}}$$

$$n = \sqrt{\frac{60 \times 15}{4}} = 15 \text{ cells in series}$$

i.e. 4 rows in parallel, each row consisting of 15 cells in series—

$$\text{Current} = \frac{30}{15 + \frac{15 \times 4}{4}} = 1 \text{ ampere.}$$

Example 7.—Seventeen cells E.M.F. ·96 volt and 4^{ω} internal resistance per cell are used to work a circuit having a resistance of 132^{ω}, of which 36^{ω} is the resistance of the sounder. If the sounder is re-wound to a resistance of 144^{ω}, what economy in battery power will result?

$$\text{with } 36^{\omega} \text{ sounder, current} = \frac{17 \times {\cdot}96}{17 \times 4 + 132}$$

$$= 82 \text{ m.a. approx.}$$

$$\sqrt{144} : \sqrt{36} :: 82 : C.$$

$$\therefore \text{current required with } 144^{\omega} \text{ sounder} = \frac{6 \times 82}{12} = 41 \text{ m.a.}$$

$$\text{Resistance of circuit} = 96 + 144 = 240^{\omega}$$

$$\therefore \text{number of cells} = \frac{240}{\frac{{\cdot}96}{{\cdot}041} - 4} = 13 \text{ cells.}$$

Hence four cells are saved.

CHAPTER III

THE MEASUREMENT OF CURRENT.

PART I.—RESISTANCE COILS.

A SET of resistance coils or a resistance box is perhaps one of the most useful and necessary adjuncts in electrical testing. These boxes contain coils of wire of definite resistance, which can be thrown into circuit or cut out at will. The wire forming the resistance coil is wound upon a bobbin in a special manner—the reason for which will receive consideration later—and is well insulated with one or two layers of silk covering wound spirally upon the conductor.

The coils are connected between a series of brass blocks cut to receive a circular peg between each block and its neighbour (Fig. 19). With all the plugs in position, the brass block forms a continuous conductor of negligible resistance between the two terminals. The removal of any plug inserts a resistance coil between the terminals of the instrument of the value marked near the two brass blocks. In the case illustrated (Fig. 19) the 2^{ω}, 3^{ω}, and 4^{ω} coils are in circuit, that is to say a resistance of 9^{ω} is introduced between the terminals. The 1^{ω} coil in this case is short-circuited by the plug.

The brass blocks are fitted upon a slab of ebonite, a material possessing very high insulating qualities. The brass blocks are recessed upon either side, beneath the plug holes, in order to provide facilities for cleaning the ebonite and removing all dust, dirt, or metallic filings, due to the continual twisting of the plugs in their holes.

The brass plugs usually take one of two forms—either a turned plug of brass or a plug of brass with an ebonite handle. The latter is the preferable form on account of the superior grip which can be obtained upon it. It is a matter of considerable importance that the plugs should fit accurately and tightly, and that the contact surfaces should be kept bright and clean. Where accuracy is required, these points must receive very careful attention, for it will be obvious that even four bad contacts in series will produce a considerable amount of resistance which should not be present. Again, this resistance will vary with the manner in which the plug is inserted. A plug should be put in firmly with a twisting motion in order to ensure a good contact. Neglect of this simple and obvious precaution often produces somewhat serious errors. Upon the other hand, resistance boxes must be handled carefully, and the use of considerable force in putting in the plugs is strongly deprecated.

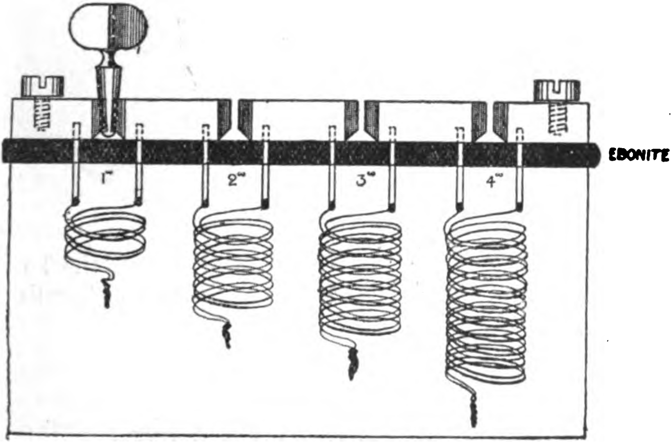

FIG. 19.—Connections and windings of a set of resistance coils.

The values given to the coils usually take the following form: 1, 2, 3, 4; 10, 20, 30, 40; 100, 200, 300, 400, etc. The right-hand set of four coils, shown in Fig. 20, has the values 1^{ω}, 2^{ω}, 3^{ω} and 4^{ω}, and it will therefore be seen that any resistance from 1^{ω} to 10 by gradations of 1^{ω} can be thrown into circuit. This is termed a set of unit coils. The centre set of coils contains 1, 2, 3, 4 units and tens—and any resistance from 1^{ω} to 110^{ω} by gradations of one ohm can thus be obtained. The large set upon the left contains a set of four "units" coils, four "tens" coils, four "hundreds" coils, and four "thousands" coils, which thus provide for any integral resistance from 1^{ω} to $11{,}110^{\omega}$.

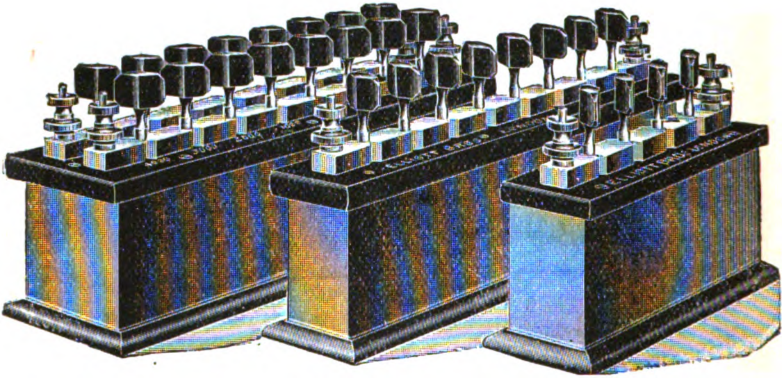

Fig. 20.—Resistance coils.

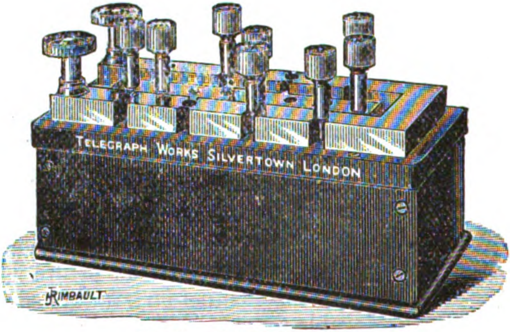

Fig. 21.—Retardation coils.

Two forms of resistance box employed in practical telegraphy are illustrated in Figs. 21 and 22. The former, known as a set of "retardation coils," on account of the purpose to which it is put (see Chapter VIII), has eight coils of the following resistances: 10^{ω}, 20^{ω}, 30^{ω}, 40^{ω}, 100^{ω}, 200^{ω}, 300^{ω}, 400^{ω}. This gives 10^{ω} to 1100^{ω} by gradations of 10^{ω}.

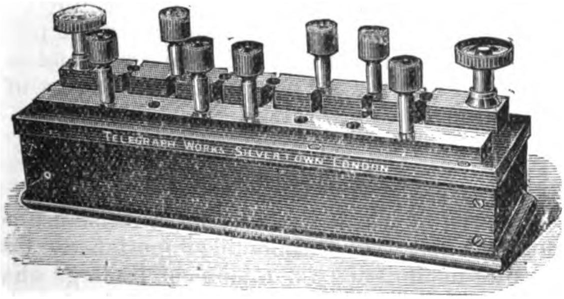

FIG. 22.—Condenser coils.

The second form used for a similar purpose is in contradistinction known as a set of "condenser coils." The resistance of its seven coils are respectively 50^{ω}, 100^{ω}, 200^{ω}, 300^{ω}, 400^{ω}, 1000^{ω}, and 2000^{ω}, *i.e.* 50^{ω} to 4050^{ω} by gradations of 50^{ω}. Both these sets of coils are used in cases where the absolute accuracy of the resistance is of very little consequence, and the form chosen is therefore simpler than those previously illustrated.

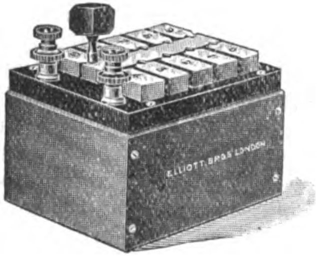

FIG. 23.—Single-plug resistance coils.

Another type of resistance box, designed to avoid the resistance due to a number of plugs in series, is illustrated in Fig. 23. This form necessitates a resistance coil for each value of resistance. To obtain 1^{ω} to 9^{ω} by 1^{ω}, nine coils are necessary, as against four coils to give 1^{ω} to 10^{ω} by the previous arrangement. The heavy central brass block forms one terminal, and the block marked 0 the other. A resistance of 1^{ω} is connected between the blocks marked 0^{ω} and 1^{ω}, 1^{ω} and 2^{ω}, 2^{ω} and

3^{ω}, etc. The introduction of the peg at 1^{ω} connects the 1^{ω} coil and at 4^{ω} the four coils between the 0^{ω}, 1^{ω}, 2^{ω}, 3^{ω} and 4^{ω} blocks. For any particular resistance, therefore, there is only one plug needed. This presents a considerable advantage where great accuracy is required. The guaranteed accuracy of this particular type is ·02 per cent.

Shunts are usually arranged in this way, and a consideration of Fig. 31, after reading the latter part of this chapter, will make this apparent.

TYPE OF WIRE TO BE USED.

The material of which the wire for a resistance coil is composed is a matter of considerable importance. Copper wire is quite inadmissible on account of its large changes in resistance with changes of temperature. Again, where a large resistance is required, the quantity of wire necessary would render the coils very bulky, or extremely fine wire would have to be employed.

The wire chosen should have a very high resistivity and a small temperature variation of resistance. The wire should not oxidize, or, in fact, be subject to any change of its resistance through age. The three alloys which are most used are German silver,* platinoid, and platinum silver. Their temperature variations of resistance are respectively ·044%, ·021%, and ·031% per degree Centigrade, as against the ·428% of copper. German silver is perhaps the oldest and most extensively employed material, whilst platinoid, manganin, and eureka are coming into ever-increasing use. Platinum silver is very expensive and is only employed for important standards. It is known to age very little and to be subject to no oxidation, and has a small and very accurately known temperature variation of resistance.

The resistivities and temperature coefficients of copper and a few well-known and frequently used alloys are given on page 79 for purposes of comparison.

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* German silver is composed of 4 parts of copper, 2 of nickel and 1 of zinc. Manganin consists of 84 parts copper, 12 parts manganese and 4 parts nickel. Platinoid is composed of tungsten nickel, copper and zinc. Eureka is a copper nickel alloy

Material.	Resistivity per cubic centimetre, in microhms.	Temperature coefficient % per degree C.
Annealed copper	1·6963	·428
German silver .	20 to 30	·044
Platinum silver .	25 to 30	·031
Platinoid . .	40	·021
Eureka . .	40	Nil
Manganin . .	42 to 46	Nil

All resistance coils are marked with the temperature at which they are correct, and this is usually made 15·5° C. or 60° F. In the case of very important standard coils the temperature variation is carefully determined, and a certificate as to this and the resistance of the coil is provided by the makers.

Gauge of Wire.

The gauge of the wire to be employed next requires consideration. Where cost and size are no object the gauge should be large, since this will give great accuracy of adjustment, and any rise of temperature due to the passage of a current through it will be reduced to the lowest possible value. Naturally a wire with a large surface will radiate any heat generated much faster than a smaller one, and its temperature will consequently be lower. In practice, however, the questions of cost and bulk are distinctly important, and therefore it is that the low resistance coils are made of a thick wire, whilst the high ones are composed of a fine wire. If fine wire were used for the low resistance coils the length of wire necessary would be short, and consequently the accurate adjustment of the actual length required would be extremely fine, and therefore subject to considerable inaccuracy. Usually, too, the currents flowing through low resistances are larger than those flowing through high resistances, and upon this account also thick wire is desirable.

Rheostats.

A form of resistance box, termed a rheostat, used by the Post Office upon telegraph circuits is illustrated in Fig. 24.

It consists of two contact arms, each of which is capable of moving over a semicircle of contact points, and three separate resistance coils and plugs. The one set of studs is consecutively marked 0, 40, 80, 120, 160, 200, 240, 280, 320, 360, and 400, whilst the other half is similarly marked, but with values ten times as great, *i.e.* 400 to 4000. By means of the nearer arm any resistance up to 400$^{\omega}$ by gradations of 40$^{\omega}$ can be inserted. With the other any resistance from 400$^{\omega}$ to 4000$^{\omega}$, by gradations of 400$^{\omega}$, may be obtained. Using both arms, any resistance from 0 to 4400$^{\omega}$ by gradations of 40$^{\omega}$ may be obtained. On the base of the instrument three coils of 10$^{\omega}$, 20$^{\omega}$, and 4000$^{\omega}$ are provided, thus bringing up the maximum resistance obtainable to 8430$^{\omega}$. The first two coils provide for gradations of 10$^{\omega}$ instead of 40$^{\omega}$; for instance 3330$^{\omega}$ would be provided by the 400$^{\omega}$ coil arm at 3200$^{\omega}$, the 40$^{\omega}$ coil arm at 120$^{\omega}$, and the 10$^{\omega}$ coil plug out. 3340$^{\omega}$ would require the 20$^{\omega}$ coil, 3350$^{\omega}$ both 10$^{\omega}$ and 20$^{\omega}$, whilst 3360$^{\omega}$ would be provided by moving the 40$^{\omega}$ coil arm to 160$^{\omega}$ and plugging up both the base coils. The 4000$^{\omega}$ coil is for use when the resistance required exceeds 4430$^{\omega}$. The connections are

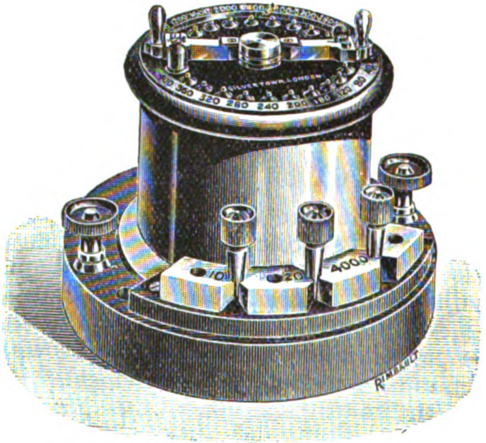

FIG. 24.—Rheostat "Q."

shown in Fig. 25, and are so obvious as to require no comment.

There are at present three forms of rheostat in daily use in the Post Office, that illustrated in Fig. 24 being known as the rheostat "C." The "B" is somewhat shorter than the "C" type, and is wound with finer wire. It is never used upon circuits worked with bichromate batteries, or upon secondary cell worked circuits, on account of the heating which almost inevitably results.

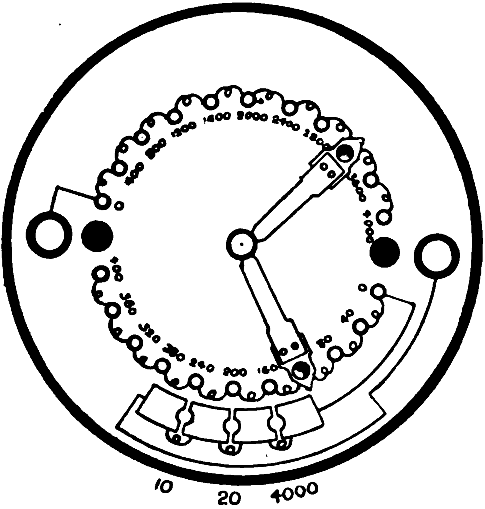

FIG. 25.—Connections of rheostat "C."

The third, or "D" form, illustrated in Fig. 26 is now the standard pattern, and possesses the merits of greater cheapness and superior efficiency of the contacts. The two radial arms each consist of strips of phosphor bronze, bent as shown, bearing down upon the circular brass contact blocks, between which the 40ω and 400ω coils are connected. In addition, 10ω, 20ω, and 4000ω, plug coils are provided, as in the "B" and "C" types.

DOUBLE-WINDING.

All resistance coils are so wound as to have the smallest possible self-inductance. This is accomplished by doubling the wire and winding it as indicated in Fig. 19. A current traversing the coil does not generate a magnetic field, and the coil has therefore no inductance. Moreover, magnets moved in the vicinity of the coils will not produce induced currents. In considering such instruments as Wheatstone bridges, it will be quite apparent that this method of winding is essential.

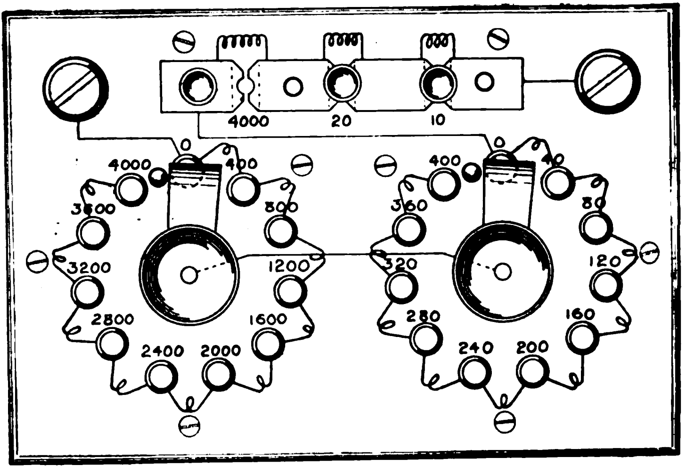

FIG. 26.—Rheostat "D."

A resistance with very small inductance may be formed by winding the coil upon a thin flat strip of insulating material. In this case the two sides of the coil are so close to each other as practically to neutralize each other's magnetic effect. This plan is very extensively adopted in telephony.

PART II.--GALVANOMETERS.

An electric current can only be measured indirectly by the effects which it produces under given conditions. Its principal effects are magnetic, thermal, and chemical, and each of these effects may be employed to detect, to compare or to measure currents.

The magnetic field round a current-conveying wire is strictly proportional to the value of the current flowing in the wire, and its direction depends upon the direction of the current producing it. If the relative values of the magnetic field at a given point produced by two successive currents in a particular conductor or series of conductors can be ascertained, then the values of the two currents producing those magnetic fields can be ascertained.

The underlying principle in all galvanometers (with the exception of the D'Arsonval types) is the comparison of the value of the magnetic field produced by a current in its coils with the earth's magnetic field.

Galvanometers may be distinguished as pointer galvanometers and reflecting galvanometers. All the instruments used in Post Office instrument rooms belong to the former class—a pointer or needle being employed to indicate the deflection. The latter class comprises all those instruments in which a mirror is fixed to the moving system to indicate the deflection by a ray of light.

TANGENT GALVANOMETER.

The merit of the tangent galvanometer lies in the fact that its indications bear a definite and simple relation to the current flowing through its coils, viz. that the current is directly proportional to the tangent of the angle of deflection. Essentially, a tangent galvanometer consists of a circular coil of wire the diameter of which is at least ten times the length of the magnetic needle suspended or pivoted at its centre. The coil is placed in the magnetic meridian, and in order to observe the deflections a light pointer of non-magnetic material is fixed at right angles to the magnetic needle. Beneath the pointer is placed a circular scale divided into degrees reading from 0° to 90° on each side of the normal E. and W. position of the pointer. The object gained by fixing the pointer at right angles to, instead of parallel with, the magnetic needle is that the normal position of the pointer at zero or 0°, and the centre of the scale is then outside instead of under the coil.

Consideration of Fig. 2 and Fig. 48, which latter shows the magnetic field due to a current flowing in a coil of wire, or solenoid as it is termed in this connection, gives the direction of the magnetic field through the coil. The magnetic needle of a tangent galvanometer lies in the magnetic meridian, *i.e.* it is held in a N. and S. position by the horizontal component of the earth's magnetic field, and this provides the controlling force. The magnetic field due to the earth and that due to the current in the coils of a tangent galvanometer are at right angles to each other. It has previously been pointed out that magnetic fields cannot cross each other (p. 10), and therefore when a current is passed through the coils of the galvanometer the direction of the resultant field is altered. If the two fields be of equal strength the resultant field lies midway between the two, *i.e.* 45° from the magnetic meridian and 45° from the direction of the field due to the coil considered by itself. If the deflecting field be less than the controlling field at the point considered the resultant field is less than 45° from the magnetic meridian. If greater, then it is over 45°. A minute magnetic needle placed at the point in question would lie along the resultant field at that point, and therefore in the three cases taken deflections of 45°, less than 45° and over 45° would be indicated by the pointer.

By making the diameter of the coil ten times the length of the magnetic needle it may still be assumed that the needle indicates the direction of the resultant field at the centre of the coil, and that therefore the tangent law still holds. But were the needle a long one its poles would move further and further from the coil as it deflects, and therefore in the case of two unequal deflections the magnetic fields would not be compared at the same point. With a small needle the magnetic field is practically uniform over the area through which the magnetic needle swings. For still greater accuracy the depth of the windings of the coil should bear to their width the ratio of $\sqrt{3}:\sqrt{2}$.

The error can be reduced to the order of $\frac{1}{100}$ of 1% by adopting the form of galvanometer devised by Helmholtz (Fig. 27) and referred to variously as the Helmholtz or Gaugain galvanometer. Two equal and parallel coils are employed with the needle lying midway between them in the line joining their centres. The distance from the centre of either coil to the needle is made equal to half the radius of either coil.*

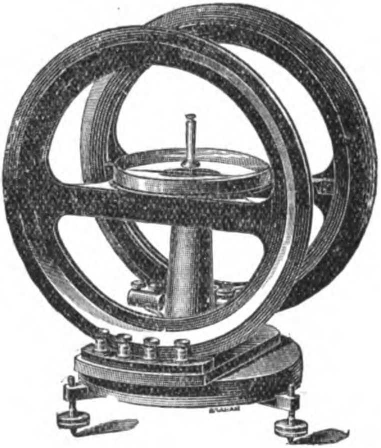

Fig. 27.--Helmholtz or Gaugain galvanometer.

In fine, the deflecting force, which is strictly proportional to the current, is at right angles to the controlling force (the horizontal component of the earth's magnetic field) normally holding the needle in the magnetic meridian. These forces are at right angles to each other, and the current producing a deflection is proportional to the tangent of the angle of deflection. If therefore a current of 10 m.a. produces a deflection of 38°, the current producing a deflection of 65° would be found thus:

$$\tan 38^\circ : \tan 65^\circ :: 10 : x$$

$$i.e.\ \cdot 7813 : 2\cdot 1445 :: 10 : x$$

$$\therefore x = \frac{2\cdot 1445 \times 10}{\cdot 7813} = 27\cdot 45 \text{ m.a.}$$

The values of tan 38° and tan 65° are obtained from a table of tangents.

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* The relation given on page 88 for an ordinary galvanometer [$C=\frac{Hr}{2\pi n}\tan a$] becomes for the Helmholtz instrument $C=\frac{5\sqrt{5}\,Hr}{32\pi n}\tan a$ where H, r, and n have the same meanings as before.

Tangent of an Angle.

In order to ascertain the value of the tangent of any particular angle, that angle should be marked off from *A O* along the quarter circle *O C* (Fig. 28). A line is then drawn connecting *A* and *O B* through the point upon the quarter-circle. The tangent of the angle is equal to the length from *O* to the point of intersection along *O B*, divided by the length of the radius of the circle. This number has only one value for any given angle, but it will be obvious that the larger the circle the greater is the accuracy with which the measurements may be obtained.

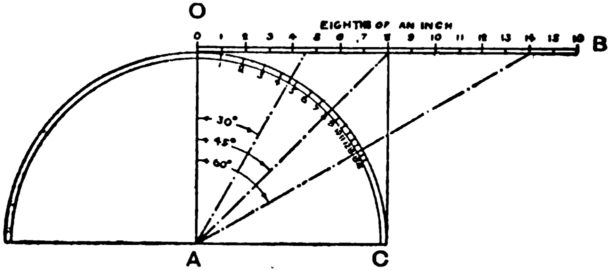

FIG. 28.—Division of galvanometer scale into tangent divisions, and illustrating the values of tan 0°, tan 30°, tan 45°, tan 60°.

In Fig. 28 the radius of the circle is one inch, and the divisions are one-eighths of an inch, therefore the tangent of any angle drawn from *A O* is equal to the length in inches of the line from *O* to the point of intersection. The tangent of 0° is 0, since the length along *O B* for angle of 0° is 0. The tangent of 45° is seen to be eight one-eighths of one inch, *i. e.* one inch. Its tangent is therefore 1. In the case of 30° it will be seen that the intersection occurs just after $\frac{4}{8}$ inch, and making a guess at the point one would say it was about half-way between $\frac{4}{8}$ and $\frac{5}{8}$, *i. e.* $\frac{4}{8}+\frac{1}{16}=\frac{9}{16}$ inch. According to this guess its tangent is then $\frac{9}{16}$ or ·56 approximately. Its actual value is $\frac{1}{\sqrt{3}}$ or ·57735. The tangent of 60° is by the same rough-and-ready process found to be $\frac{14}{8}$ or 1·75.

Its actual value is $\sqrt{3}$ or 1·73205. It will be noticed that tan 60° is exactly three times as large as tan 30°, a fact which may readily be verified by using a pair of dividers upon Fig. 28. From *O* to 14 is exactly three times the distance from *O* to the point marked 30°. The tangent of 90° is infinity, since the lines *A C* and *O B*, being parallel, never meet. *A O* is of finite length and *O B* infinite.

Having defined the actual values of the tangents of the various angles, it is an easy matter to show the relative values of the divisions. For the purpose of simplifying the previous calculations the divisions bore a simple and direct relation to the radius of the circle, but this is by no means essential. The length of a division upon the line *O B* may be of any chosen value so long as all the divisions are of equal length.

The tangents of the angles of deflection are in each case the particular length marked off along *O B*, divided by the radius of the circle. The radius of the circle is the same in each case, therefore the tangents of the angles of deflection are directly proportional to the lengths marked off from *O* along *O B*. These lengths are, however, divided into equal divisions, consequently the divisions marked off along *O B* are proportional to the tangents of the angles, and the current producing any deflection on a tangent galvanometer is therefore directly proportional to the number of divisions on the circle indicated by the needle or pointer.

TANGENT SCALE.

The construction of a tangent scale therefore consists (i) in drawing a straight line at right angles to the line joining the centre and zero of the scale, (ii) in dividing it into equal divisions of any convenient length, and (iii) in marking and numbering consecutively the points at which lines drawn from each division intersect the circle of the scale. In this way, repeated reference to a table of tangents is avoided, since the current is then directly proportional to the number of divisions indicated by the pointer.

THEORY OF TANGENT GALVANOMETER.

The deflecting force is the magnetic field due to the current in the coils, and the controlling force which tends to hold the needle in the magnetic meridian is the earth's field. These forces are at right angles to each other, and when the needle comes to rest under their combined action:—

Deflecting force (F) = Controlling force (H) × tan a where tan a is the tangent of the angle of deflection.

By definition, unit current flows in an arc of 1 cm. length and radius when the magnetic field generated at its centre is 1 gauss. The magnetic field F at the centre of a coil of r cm. radius with n turns of wire is

$$F = \frac{\text{length of wire}}{(\text{distance of wire from centre})^2} = \frac{2\pi rn}{r^2} = \frac{2\pi n}{r}$$

with a current of C units $F = \dfrac{2\pi nC}{r}$.

When the needle comes to rest $F = H \tan a$, where a is the angle of deflection from the magnetic meridian.

$$F = \frac{2\pi nC}{r} = H \tan a$$

$$\therefore\ C = \frac{Hr}{2\pi n} \tan a.$$

ABSOLUTE MEASUREMENT.

The value of H can readily be determined* from the rate of swing of a magnet in the horizontal field, and from its dimensions and the deflection produced on a magnetometer and its distance therefrom.

Having determined H, and knowing "n" and "r," the value of the current due to a deflection a can be calculated. Such a measurement is termed an absolute determination, since it has been made independently of existing electrical standards or units. A galvanometer used in this way is termed an absolute galvanometer.

It should be added that in all absolute determinations the value of the current is in C.G.S. units which require to be divided by ten to give the current in amperes.

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* Stewart and Gee's *Practical Physics*, Vol. II. chap. ii. and chap. vi., or Grays' *Absolute Measurements in Electricity and Magnetism*, chap. ii.

As an example, the current producing a deflection of 45° (tan 45°=1) on a Post Office tangent galvanometer (with the coil in the magnetic meridian and not from the skew scale zero), and taking *H* as ·18, would be—

$$= C\frac{\cdot 18 \times (6\tfrac{5}{16} \times 2\cdot 54)}{2 \times 3\cdot 1416 \times 1400} \times 1 \begin{array}{l} = \cdot 000361 \text{ units} \\ = 3\cdot 61 \text{ m.a.} \end{array}$$

THE P.O. TANGENT GALVANOMETER.

The base, frame, and needle box (Fig. 29) are of well lacquered brass. The magnetic needle, provided with a

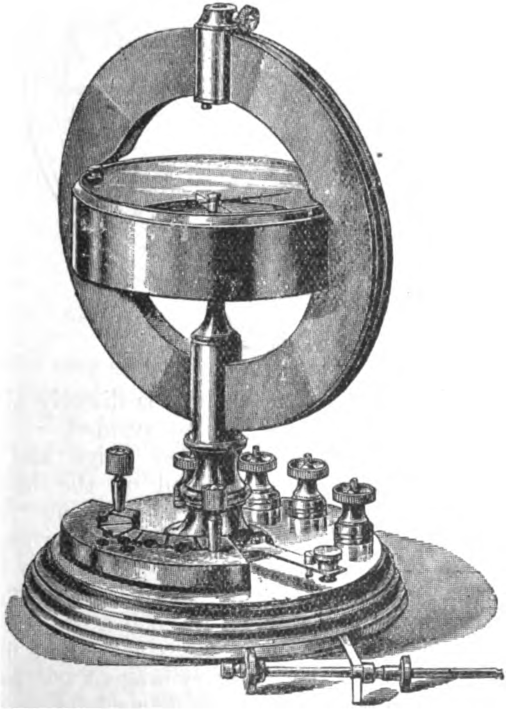

FIG. 29.—P O. Tangent galvanometer.

central cap of agate, is pivoted upon an upstanding steel point in the centre of the box. The light aluminium pointer is fixed at right angles to the needle and a mirror is fixed close to the scale in order to avoid parallax error, *i. e.* the possibility that a deflection of, say, 100 divisions is read as 99 or 101, according to the position of the observer's eye above the needle. By taking the reading when the pointer and its image in the mirror beneath coincide it is ensured that the eye is directly above the needle and parallax error is thereby avoided.

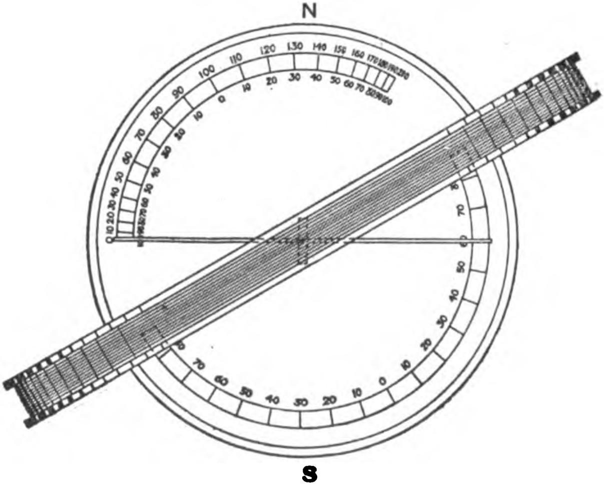

Fig. 30.—Skew scale.

In order to obtain an extended range and greater accuracy of measurement the coil of the instrument (Fig. 30) is twisted through an angle of 60° from the magnetic meridian. The deflecting force is at right angles to the plane of the coil, and therefore tends to pull the S. pole of the needle to the N.W. and the N. pole to the S.E. If the current is applied in such a direction as to deflect the pointer off the scale, the current must be reversed, whereas with an ordinary tangent galvanometer the deflection may be read upon either side of zero. This is, however, of little consequence since the reversal of the current when necessary is readily effected.

The lower half of the scale (Fig. 30) is marked in degrees, whilst the top side of the upper half is marked in divisions representing equal currents. The scale is prepared upon both sides of the ordinary zero in the same manner as in the case of the ordinary patterns, and it will be observed that the divisions are largest and most open at the centre of the scale. Deflections near to 100 can therefore be read with very great accuracy, the most accurate reading being obtained at 110 divisions. For deflections of less than 30° from the skew zero, the skew scale has no advantage over the ordinary pattern, but for deflections larger than this the skew scale is distinctly beneficial. The divisions marked upon the bottom side of the upper half of the scale were used in connection with the battery testing instrument.

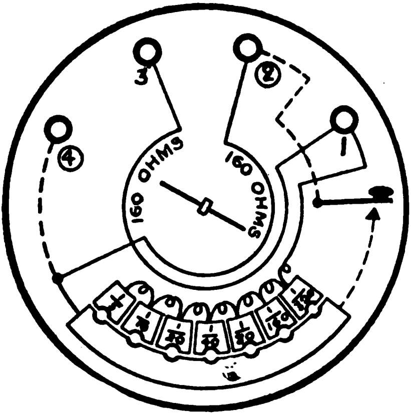

Fig. 31.—Connections of P.O. tangent galvanometer.

The controlling magnet and its stalk are shown by the side of the instrument (Fig. 29). The base of the stalk below the flange fits into the holder at the top of the ring and is clamped by the thumbscrew so that the magnet may be raised or lowered upon the stalk without risk of an accidental twist, it being imperative that the magnet shall lie in the magnetic meridian.

The instrument is differentially wound and is provided with seven shunts. Its connections are shown in Fig. 31 and a summary of the various details is given below. It may be added that a current entering at 4-circle passes through one coil of the galvanometer to 2-circle, which is usually connected by a brass strap to 3 and through the second coil to terminal 1. The depression of the key connects a short length of copper wire across the 2-circle 4-circle coil, or, in other words, "short-circuits" it.

DETAILS OF P.O. TANGENT GALVANOMETER.

Breadth of windings	$\frac{11}{32}$ inch
Depth of windings	1 inch
Mean radius of windings	$6\frac{15}{16}$ inches
Diameter of inmost layer of windings ...	$5\frac{15}{16}$ inches
„ „ outer „ „ „ ...	$7\frac{15}{16}$ inches
Length of magnetic needle	$\frac{7}{8}$ inch
„ „ pointer	5 inches
Number of convolutions (coils in series)	1400
Resistance (coils in series)	320ω
Angle of maximum sensitiveness ...	110 divisions
Maximum deflection	200 divisions
Standard adjustment (coils in series)	1 division $=\frac{1}{80}$ m.a.

SHUNTS.

Name of shunt.	Value of 1 division. m.a.	*Value of 110 divisions. m.a.*	Value of 200 divisions. m.a.	To be used.		Resistance of shunt.	Combined resistance.	Compensating resistance.*
				From m.a.	To m.a.			
—	$\frac{1}{80}$	*1·375*	2·5	0	2·5	—	320ω	—
$\frac{1}{5}$	$\frac{1}{16}$	*6·875*	12·5	2·5	12·5	80ω	64ω	256ω
$\frac{1}{10}$	$\frac{1}{8}$	*13·75*	25	12·5	25	35·56ω	32ω	288ω
$\frac{1}{20}$	$\frac{1}{4}$	*27·5*	50	25	50	16·84ω	16ω	304ω
$\frac{1}{40}$	$\frac{1}{2}$	*55*	100	50	100	8·205ω	8ω	312ω
$\frac{1}{80}$	1	*110*	200	100	200	4·051ω	4ω	316ω
$\frac{1}{160}$	2	*220*	400	200	400	2·013ω	2ω	318ω
$\frac{1}{320}$	4	*440*	800	400	800	1·003ω	1ω	319ω

* Compensating resistances are not provided.

DIFFERENTIAL WINDING.

It will be noticed that there are two coils wound upon the P.O. tangent galvanometer, the 4-circle 2-circle coil being one, and the 3-1 coil the other. These two coils are equal in resistance, length, and position with respect to the needle. A current of any particular value would therefore produce the same deflection in traversing the 4-circle 2-circle coil as in traversing the 3-1 coil. When the current traverses both coils in the direction 4-circle to 1 the effect upon the needle is doubled. If, however, the terminals 4-circle and 1 are connected together and the positive pole of a battery is connected to them whilst its negative pole is connected to 3 and 2-circle connected together, no deflection will be produced. The current in each coil will have the same value since their resistances are equal. The current flowing from 4-circle to 2-circle will, however, tend to generate a magnetic field opposite in direction to that which the current flowing from 3 to 1 tends to produce. Since each coil has the same current flowing and its length and distance from the needle is the same, no effect upon the needle can be produced. It is quite impossible for two magnetic fields of opposite direction simultaneously to exist in one place, hence no magnetic field whatever is generated by the arrangement described. Any type of galvanometer may be differentially wound, and therefore a differential galvanometer may be defined as a galvanometer having two windings of equal resistance and equal but opposite effect upon the magnetic needle, when the same value of current circulates in each coil in contrary directions.

CONTROLLING MAGNET.

The object of the controlling magnet is to vary the sensitiveness of the instrument. The value of any current indicated by the galvanometer depends directly upon the value of the horizontal component of the earth's magnetic field. If this value is large then a correspondingly large current is required to produce a given deflection. If the controlling magnet is placed with its North pole facing the

North pole of the needle the value of the earth's field is reduced, whilst if it has its South pole opposite the North pole of the needle the value of the earth's field is correspondingly increased. It will be obvious that the sensitiveness of the instrument is reduced if the controlling magnet is so placed as to attract the needle backwards, from the deflection produced, towards zero. If, on the other hand, there is repulsion, then the sensitiveness is increased. The extent to which the sensitiveness is increased or reduced is dependent upon the proximity of the controlling magnet to the needle. The nearer they approach the greater is the effect produced.

The controlling magnet should always be placed parallel to the needle, *i. e.* it should lie in the magnetic meridian. Unless this condition is observed the needle of the galvanometer may not point to the zero of the scale. In practice the controlling magnet is invariably used to increase the sensitiveness of the galvanometer; its North pole therefore facing the magnetic North.

GALVANOMETER CONSTANT.

The deflection obtained on a tangent galvanometer depends upon the value of the controlling force, and this is subject to variation by the presence of local masses of iron such as girders, hot-water pipes, etc. Its value can only be assumed to be constant for a particular place during a particular set of measurements. The absolute determination of current is a difficult process involving great care, knowledge, and experimental skill, and it is therefore unsuited for everyday purposes. It has been shown that currents can be compared with the aid of a tangent galvanometer, but to give the value of a current in milli-amperes involves the use of a known current. At one time a standard Daniell cell was employed to provide a known E.M.F. ($1{\cdot}08^{v}$). Knowing the total resistance of the circuit in which the cell and galvanometer were included, the current flowing was also known, and thus the value corresponding to any given deflection could be stated in milli-amperes. It is convenient to have a standard adjustment, and with the aid of the controlling magnet 1 m.a. on the two coils in series was and is made to be represented by a deflection of 80 divisions.

The constant of a galvanometer may be defined as the number by which the deflection must be multiplied to give the current in milli-amperes.

The Daniell cell needed some care in making up, and consequently it gave place to the sealed standard cell arrangement. This consists of a single dry cell with a resistance coil of 1144^{ω} placed in a small wooden box, the lid of which is protected by a special seal. The box carries a brass frame in which is inserted a card giving the value of the deflection which must be produced upon a galvanometer in order that 80 divisions may represent 1 m.a., and also the date upon which the cell is to be returned for verification. It is returned to the Engineer-in-Chief's Office every three months, where the box is opened and the E.M.F. of the cell carefully measured. Should the E.M.F. have diminished, the value of the deflection necessary is re-calculated and entered upon a new card, which is substituted for the old one.

As the internal resistance of the standard cell is negligible, a current of 1 m.a. would be produced if its E.M.F. happened to be precisely 1·464 volts. The relation between its actual E.M.F. and the corresponding deflection which must be obtained in order that 80 divisions shall represent 1 m.a. is readily obtained.

For example, with an E.M F. of $1{\cdot}457^{v}$—

$$\text{current} = \frac{1{\cdot}457}{1144 + 320} = {\cdot}995 \text{ m.a.}$$

If 1 m.a. = 80 divisions,
then ·995 m.a. = 80 × ·995 m.a. = 79·6 or 79½ divisions.

The advantage gained by inserting the resistance of 1144^{ω} in the box itself is that, should the cell terminals accidentally be short-circuited, the resulting current (about 1¼ m.a.) will not cause a large permanent change in the E.M.F. of the cell such as would result from a direct short-circuit of the cell itself.

TAKING CONSTANT.

In taking the constant the following operations are necessary:—

1. Remove the controlling magnet and place it some distance away.

2. Turn the instrument until the pointer stands opposite the zero of the outer scale. (Note that the needle is not bent, by observing if the other end lies over 60° on the lower right-hand scale of degrees.)

3. Join up the standard cell by means of the switch and observe the deflection. (The cell should only be kept on long enough to obtain a reading, and the switch should therefore be opened as quickly as possible.)

4. The magnet should be slid to the top of the stalk and—

(*a*) If the deflection obtained without the controlling magnet is *above* the value shown upon the standard cell card the stalk should be placed in its socket and its North pole turned towards the South (*i. e.* its North pole opposite the needle's South). It should then be slightly twisted until the needle is exactly at zero.

or (*b*) If *below*, the North pole of the magnet should face North (*i. e.* its North pole opposite the needle's North). It should then be slightly twisted until the needle is exactly at zero.

5. The stalk should then be clamped by the socket screw.

6. The standard cell should be applied, and the magnet lowered upon the stalk until the requisite deflection is obtained. The cell should be kept on for as short a time as possible, hence it is preferable to make a series of tests rather than to keep the cell running the whole time the magnet is being lowered.

In connection with these operations, the use of the key which short-circuits the 2-circle 4-circle coil when depressed is required in order to quicken the processes detailed in 3 and 6. The joining up of the standard cell would cause the needle to swing well past its proper deflection, and it would oscillate above and below this latter point for some time before coming to rest. By momentarily short-circuiting one coil of the galvanometer the needle is checked in its swing and is urged to return to a lower deflection. By suitable tapping upon this key at the moment of a swing in the direction of increased deflection the needle can very rapidly be brought to rest. With a very little practice the needle can be brought to rest with considerable expedition. It will be obvious that the same procedure may be applied to any other form of test with this particular instrument.

It occasionally happens that the pointer of the tangent galvanometer is not accurately set with respect to the needle. When one end of the pointer stands at the zero of the outer scale the other end should stand at 60° on the opposite scale of equal degrees. This proves that the pointer is straight, but not that it is at right angles to the magnetic needle. Where such a defect is suspected a deflection of 200 divisions should be obtained by applying about 50 or 60 volts through a sufficient amount of resistance. The resistance of the circuit should then be doubled by adding resistance equal to the galvanometer resistance (320^{ω}), battery resistance, and that previously introduced. If the deflection is not exactly 100 divisions, the needle requires adjustment. The pointer should be bent and set at zero, and the whole operation repeated until doubling the total resistance of the circuit exactly halves the deflection.

PAUL'S UNIPIVOT INSTRUMENTS.

The advantages of an instrument which is independent of the value of the earth's magnetic field and which does not require the adjustment of its constant upon each occasion upon which it is used will be apparent. This result may be accomplished by providing a constant magnetic field and a suitable spring to provide the controlling force to oppose the turning force of a movable coil placed within the field. Paul's unipivot galvanometer

(Fig. 32) consists of a large permanent magnet between the poles of which there swings a coil of insulated copper wire wound upon a light copper frame. The magnetic field across the coil is rendered uniform by placing a spherical wrought-iron armature between the poles, so shaped as to maintain a perfectly uniform air gap in which the coil moves. The coil (Fig. 33) is carried on a single pivot resting on a jewel cup at the centre of the armature.

The direction of the magnetic field generated by the current is at right angles to the plane of the coil, and the tendency is therefore for the coil to turn into such a position that its lines of force are in the same direction as the permanent magnetic field. This turning force is opposed by the torsion which is put upon the spring when the coil turns, and thus provides the controlling force. The magnet is subjected to a series of processes which have the effect of "ageing" it and thus rendering it practically constant. The magnetic field being uniform throughout the area through which the coil moves, and the opposition of the spring being proportional to the angle through which it is turned, it will be recognized that

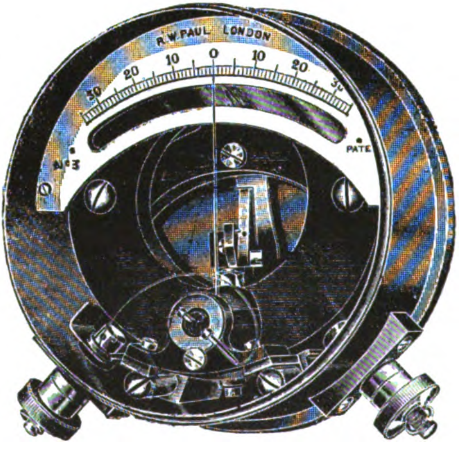

Fig. 32.—Paul's Unipivot galvanometer.

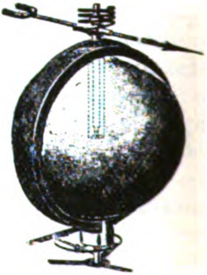

Fig. 33.—Unipivot coil and core.

the current will be directly proportional to the angular deflection of the coil. The scale will therefore be a uniform one with equal divisions representing equal currents. By suitable design the constant of the instrument may be given a particular value, and in the case of all the Paul instruments the value is $\frac{1}{500}$ m.a. per division.

The instrument may, when necessary, be set to zero by means of the small projecting lever to which the torsion spring is attached. A further device has been added by which the coil may be raised and clamped for transport.

The function of the light copper frame upon which the coil is wound is to damp the vibration of the coil, and thus to render the instrument dead-beat. The motion of the copper frame across the intense field of the permanent magnet causes a current to be induced in the frame. This current circulating round the frame produces a magnetic field which combines with the permanent field to oppose the motion of the frame, to which motion the induced current is due. Since the value of the current depends upon the rapidity of the motion of the coil, a very considerable opposition to sudden motion is experienced. In this way the time taken for the needle to come to rest after being deflected is reduced and the needle comes to rest with few oscillations, and therefore a large number of readings may be taken in a given time.

Consideration will show that instruments of this type may have their scales marked in milli-amperes and be employed for the measurement of currents. Such an instrument is then termed a milli-amperemeter. The advantages of such instruments as compared with the use of a tangent galvanometer are sufficiently obvious.

HORIZONTAL GALVANOMETER.

This instrument (Fig. 34) consists of a coil of wire with a very large number of turns and having a comparatively long magnetic needle pivoted at its centre. The pointer is fixed at right angles to the needle, and a corresponding counterpoise provided upon the opposite side of the needle. The whole of the moving parts can be raised and clamped at will by moving the projection outside the brass case, thus avoiding damage during transport.

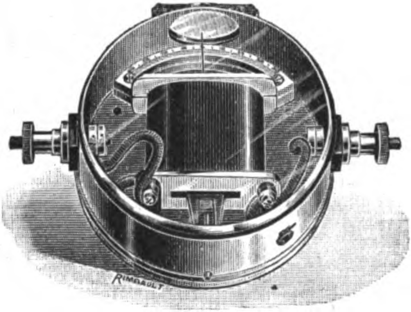

FIG. 34.—Horizontal galvanometer used in conjunction with the Wheatstone Bridge.

It can be used only to detect the presence and direction of a current, since, unlike the Paul instrument, its scale degrees are not proportional to the current, nor owing to its dimensions does it obey the tangent law.

Q AND *I* DETECTOR.

The "*Q* and *I*" part of the title is a survival of the days when the terms "quantity" and "intensity" were in general use. The detector (Fig. 35) is provided with two windings, having resistances of 100^{ω} ("intensity" coil), and $\cdot 2^{\omega}$ ("quantity" coil), the latter being provided with a $\frac{1}{8}$ shunt inserted by means of the switch upon the top of the case. The needle is of the Varley induced type (see Fig. 95), but the permanent magnets are disposed in

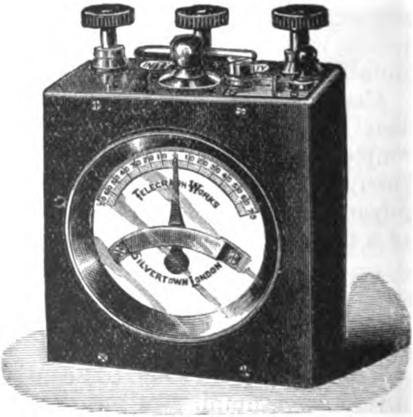

FIG. 35.—*Q* and *I* detector.

a slightly different manner in order to economize space. The central terminal is common to both coils, and in a form of detector, used in connection with the Webb and Thompson railway staff system, a $\frac{1}{10}$ shunt and switch is added to the 100^{ω} coil.

The figures of merit are specified as follows:—100^{ω} coil, 9·3 m.a. should produce a deflection of from 40° to 50°; $\cdot 2^{\omega}$ coil, 139 m.a. should produce a deflection of from 20° to 30°.

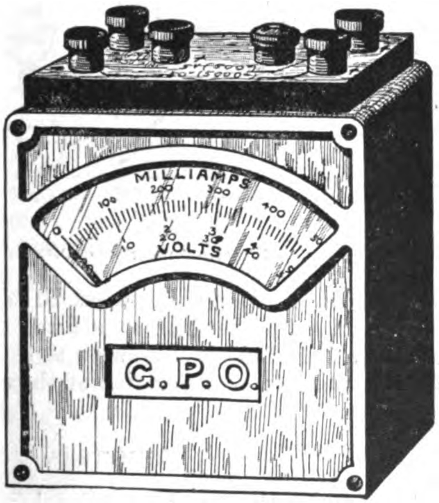

FIG. 36.—Detector No 2.
(Note. An extra terminal has been added to give current reading from 0 to 50 ma.)

This instrument is extensively used by linemen for tracing instrument faults, numbering wires, rough battery tests, and many other similar purposes. It cannot, of course, be used for current measurement; and beyond the fact that a larger current is required to produce a deflection of 30° than 20°, and that the constant of the instrument is fairly permanent, its indications are valueless.

DETECTOR No. 2.*

This instrument is a moving coil voltmeter and milliamperemeter of robust construction contained in an aluminium case, and provided with a leather case so arranged that the instrument may be used without withdrawal. It will be observed that the coil is placed at an angle to instead of in the line joining the soft iron pole pieces. This gives extended range of measurement. The moving coil has a resistance of 60^{ω}, and unshunted gives a full scale reading with 10 m.a. and with the $\frac{1}{50}$ and $\frac{1}{5}$ shunts with which it is fitted 500 m.a. or 50 m.a. Its use as a voltmeter reading 0 to 5^{v} and 0 to 50^{v} will be apparent after a consideration of the subsequent chapter.

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* *P.O. Electrical Engineers' Journal*, Vol. III. p. 234, and Vol. IV. p. 278.

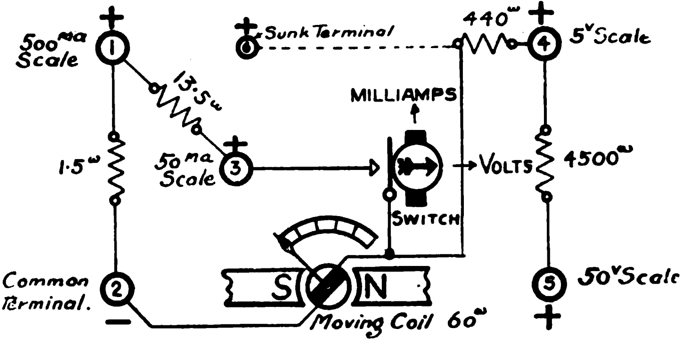

Fig. 37.—Connections of Detector No. 2.

AMMETERS.

To measure larger currents such as those in charging secondary cells, instrument reading in amperes are employed. Many of these are of the moving coil type, the main current being diverted through a shunt. The arrangement is illustrated in Fig. 38. The resistance employed as shunt is low and is capable of carrying heavy currents. With a Weston

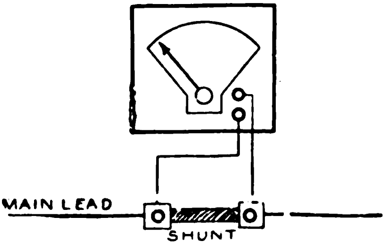

Fig. 38.—Ammeter.

instrument reading from 0 to 50 amperes, the resistance is about ·00435$^{\omega}$. The arrangement may be regarded as consisting of a voltmeter (the actual instrument) which indicates the difference of potential across the shunt, which in turn depends upon the current flowing through the shunt.

It may be added that by using a number of shunts and a simple form of switch, the current can be measured in several circuits at will with a single instrument. It will also, perhaps, be useful to add that the leads connecting the shunts with the instrument should not be shortened, any slack being neatly coiled up, since the instrument is calibrated with the resistance of these leads in circuit.

By providing the index of an ammeter with a pen, and by a suitable clock causing a paper chart, carried on a drum making one revolution per 24 hours, to move beneath the pen, it is possible to obtain a permanent and continuous record of the current passing through the instrument. Such an instrument, termed a recording ammeter, is used to obtain a continuous record of the currents taken by the various power leads on the secondary cell system. It need only be added that the sheet is divided up into hours along its length, and into amperes across its width.

Moving Iron and Hot Wire Ammeters.

There are three main types of ammeter of which only the moving coil type has so far been considered, and it may therefore be useful to describe briefly the principles involved. The other types are those in which the motion of an iron armature is employed, and those in which the heating of a wire by the passage of the current is utilized.

If a solenoid be provided with an iron core attached to a fixed spring balance so disposed that a current through the coil draws down the plunger, the scale of the balance could be marked with the value of the current corresponding in the weight pulled. This is the arrangement and principle of the Kohlrausch ammeter. In the Westinghouse type the motion of the armature towards the edge of the coil is opposed by gravity. In several other types a similar principle is employed, viz. the tendency of the iron to move from a comparatively weak to a stronger magnetic field, which is opposed by the weight of the moving system.*

In hot wire instruments a proportion of the main current is passed through a wire which becomes hot and increases in length under the action of the current. This extension in length is employed to move the pointer.

REFLECTING GALVANOMETERS.

The original galvanometer of the reflecting type was invented by Lord Kelvin, formerly Sir William Thomson, and consists of a circular coil of wire, in the centre of which is fixed a removable copper tube carrying a small circular mirror suspended from its centre by an extremely short length of silk. Upon the back of the mirror two or three short pieces of magnetized steel are fastened. The coil is placed in the magnetic meridian, and opposite it a lamp and scale for observing the deflection.

A beam of light is directed by a lens on to the mirror, which in its normal position reflects a circular beam of light on to the scale. When the mirror is deflected by the smallest amount the spot of light moves along the scale. This is roughly illustrated in Fig. 39, where it will be observed that a very small angular deflection of the mirror has produced a large alteration in the position of the spot of light upon the scale. The beam of light is practically a pointer of indefinite length, and by increasing the distance from the mirror to the scale the sensitiveness of the arrangement may be greatly enhanced. The usual distance employed is a metre, *i. e.* rather more than a yard. If the scale divisions are equal, the conditions shown in Fig. 28 are fulfilled, and the current may therefore be assumed to be proportional to the number of divisions passed over by the spot of light. If the angular deflection is extremely small the tangent law may be assumed to apply, since the corrections necessary when the dimensions widely differ from those laid down for an ordinary tangent galvanometer are extremely minute.

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* For descriptions of various patterns see Maycock's *Electric Light and Power Distribution*, Vol. I. p. 374.

Since the angle at which the light strikes the mirror is equal to the angle at which it is reflected, the value of the deflection is doubled. This introduces a very small correction, which for most practical purposes is ignored.

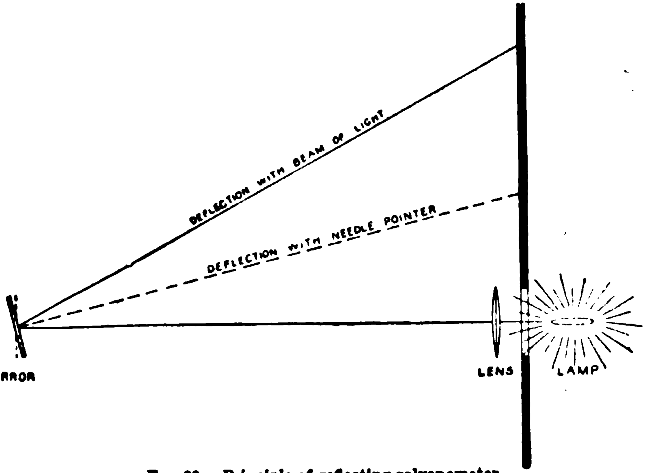

FIG 39.—Principle of reflecting galvanometer.

The actual error which is made is the assumption that half the tangent of the angle between the beam of light and its reflection is equal to the tangent of half the angle of deflection. In an absolute calculation the error amounts to rather less than ⅓ % for a 3° deflection of the mirror. In a comparative test the error would be far less.

DAMPING.

In the earlier forms of reflecting galvanometer the time taken for the needle to come to rest after being deflected was considerable, so that, in any given time, a comparatively small number of measurements could be made. This defect has been remedied in the more modern forms of instrument by various devices. The copper tube mentioned in the description of the original galvanometer was provided for the purpose of damping these vibrations, but it was only partially successful. The principle upon which it depends is that when a conductor moves across a magnetic field or when a magnetic field moves across a conductor an E.M.F. is generated. If the conductor be a complete circuit a current is generated, and this current produces a magnetic field in such a direction as to oppose the motion to which it owes its origin. The value of the induced E.M.F., and consequently of the current produced, depends upon the rapidity of the motion; therefore, the more rapid the motion the greater is the retarding tendency or opposition (termed damping) to that motion. With

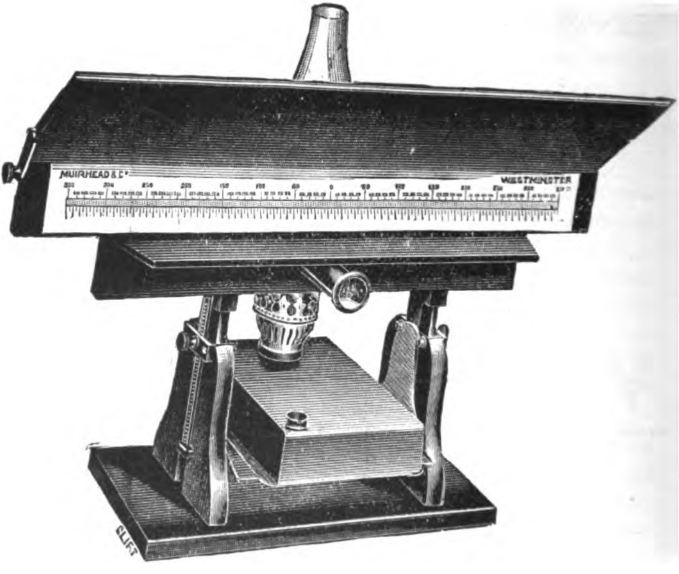

Fig. 40.—Lamp and scale for use with reflecting galvanometers.

reflecting galvanometers, the magnetic needles upon the back of the mirror carry with them a small magnetic field which is united with that of the earth. When the needle is deflected, its magnetic field cuts through the copper tube, and eddy currents, which oppose the rapid motion of the mirror, are generated in the tube.

The opposition offered by the air contained in the restricted space of the copper tube to the rapid motion of the mirror through it also adds its damping effect. In one type of galvanometer the mirror is placed in oil.

A galvanometer in which the damping is very great is termed "*dead-beat.*"

A lamp and scale are illustrated in Fig. 40. It may be remarked that the circular spot of light thrown upon the scale is crossed by a fine vertical line. This vertical line is produced by a vertical scratch, or a fine wire upon the lens. Its object is to render the reading of the deflection easier and consequently more accurate. The dark line down the centre of the spot of light is adjusted by means of the controlling magnet to fall upon the zero of the scale, and the value of any deflection is read as the number of the division upon which the line falls. In some cases a thin vertical slit of light is used instead of a circular beam, but this is considered scarcely so satisfactory as the round spot It may also be remarked that the flame of the lamp should present its edge to the lens and not its breadth.

KELVIN (OR MOVING MAGNET) REFLECTING GALVANOMETERS.

One of the numerous forms given to this instrument is shown in Fig. 41 with the moving system drawn to an enlarged scale at the side (Fig 42).* An aluminium wire, *AW*, carries the two compound needles, *SN*, *NS*, (which are arranged to form an astatic combination), the vane, *V*, of aluminium foil, and the mirror, *M*. This constitutes the moving system, and is suspended from the screw, *TS*, by a very fine fibre, *F*, of cocoon silk. The four coils are mounted on two-hinged frames to facilitate adjustment, or inspection of the needles. The four coils are connected in series, but the direction of the current in the lower pair of coils is opposite to that in the upper coils, so that they combine to deflect the needles in the same direction.

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* Taken from W. Perren Maycock's *Electric Light and Power Distribution*, Vol. I. p. 299.

The vane, *V*, moves in a small and almost enclosed chamber, thus damping or retarding the oscillations of the needles. Careful levelling is necessary to secure that the needles and vane may hang quite clear.

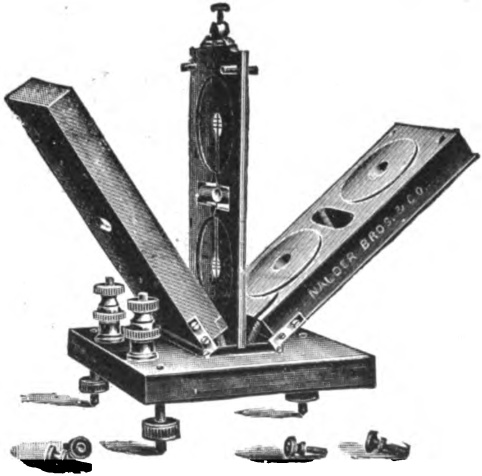
NALDER BROS. & CO.

FIG. 41.—Simple form of Kelvin galvanometer.

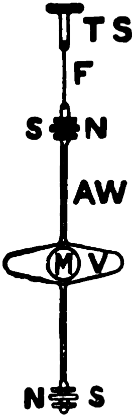

FIG. 42.—Needles and mirror.

Frequently the coils are wound differentially, the final adjustment being made by a small sliding coil which can be moved towards or away from one of the needles.

A high-grade instrument with a long suspension and controlling magnet and wound to a resistance of 100,000$^{\omega}$ is shown in Fig. 43. Special precautions have been taken to secure very high insulation, but otherwise it differs little from the instrument previously described.

ASTATIC NEEDLES AND SYSTEMS.

An astatic combination of needles may be employed in many types of galvanometer for the purpose of increasing the sensitiveness. In its simplest form it consists of two needles of equal length and equal pole strength, but with opposite poles facing each other, rigidly connected together.

The arrangement shown in Fig. 44 constitutes an astatic combination, but frequently the number of needles exceeds two. The qualification for a system or arrangement of needles to be considered astatic is that the earth's directive control shall have been reduced to a minimum. With the aid of the controlling magnet it is possible to reduce it to zero, and the torsion on the cocoon fibre then becomes the controlling force, but this condition gives the needles too unstable a zero for practical use. The ballistic galvanometer illustrated in Fig. 46 has four needles arranged to form an astatic combination.

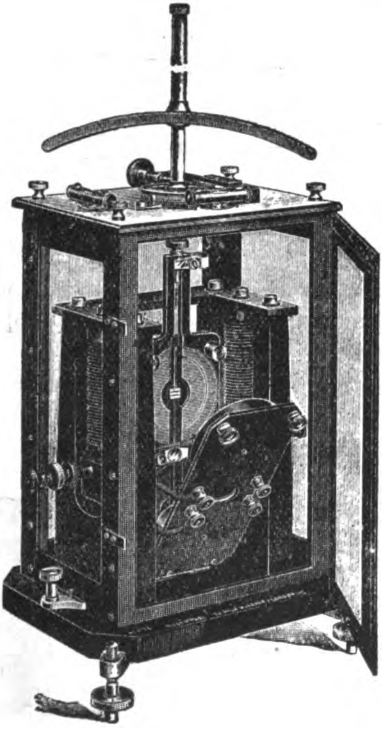
FIG. 43.—High-grade Kelvin galvanometer.

D'ARSONVAL (OR MOVING COIL) REFLECTING GALVANOMETERS.

In these instruments the pointer is replaced by a mirror, and the controlling force is the torsion on the suspending wires, which serve also to convey the current to and from the coil. The Holden-D'Arsonval galvanometer (Fig. 45) has a circular compound magnet with curved poles, between which the moving coil, wound on a light silver frame, is suspended by flat phosphor-bronze wires. The field is concentrated and rendered uniform across the coil with the aid of the cylindrical soft-iron armature. The silver frame forms a closed circuit of low resistance, and in moving it cuts the intense permanent field, and currents

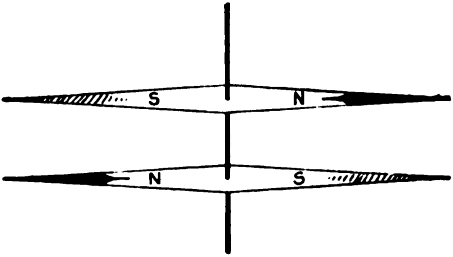

Fig. 44.—Astatic pair of needles.

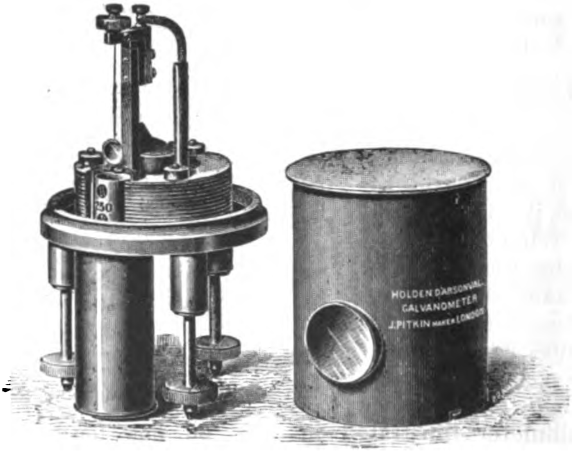

Fig. 45.—Holden-D'Arsonval galvanometer.

are induced in it which by Lenz's law oppose the motion to which they owe their origin, and, since their value depends upon the rapidity of the motion of the coil, a very considerable opposition to sudden motion is experienced. The instrument is therefore dead-beat, and this constitutes one of its advantages; but its greatest advantage lies in the fact that, owing to the large value of the permanent field, it is not affected by external magnetic fields. It is not, however, so sensitive as the highest types of Kelvin galvanometer.

There are many forms of instrument, as, for example, the robust Paul single-pivot instrument, with its spiral spring control, thus dispensing with the somewhat fragile suspension wires. In the Ayrton Mather instrument * the coil is made very narrow, and the soft-iron armature is dispensed with. The coil is enclosed in a silver tube to secure damping. In the Crompton galvanometer † the coil is hung on two suspending wires placed side by side and close together. At the upper end the distance between the ligaments may be varied to increase or reduce the sensitivity as required.

BALLISTIC GALVANOMETER.

The ballistic galvanometer differs from other types of galvanometer in the kind of needle employed. It is used for measuring the quantities of electricity discharged by condensers or electromagnets, and not usually for measuring currents. It might therefore be more correctly termed a coulomb-meter. The needles are heavy and cylindrical, the object being to secure a weighty moving part and at the same time to reduce the friction caused by its movement as much as possible. With this object in view, the suspending silk is often made of considerable length. To give a correct indication it is essential that the whole of the discharge to be measured shall have passed through the instrument before the needle has sensibly moved from its position of rest. The quantity of electricity discharged

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* *Outlines of Electrical Engineering*, by Simmons, p. 254.

† *Ibid.*

through it is then proportional to the value of the swing produced. The period of time taken for the needle to swing from side to side is made as large as possible, and in this respect it is diametrically opposite to a dead-beat galvanometer.

One coil of the instrument (Fig. 46) has been swung open upon its hinge in order to show the construction of the needles. The central pair of needles consists of two tubes of steel with spherical extremities. The two open ends of the tubes are brought together and both are split at each side, one side being made into a North pole and the other into a South; thus the arrangement corresponds to an ordinary magnetized needle, and in its normal position the slits are in a straight line passing through the centre of, and at right angles to, the plane of the coils. The needles at the top and at the bottom are similar to one of the needles at the centre, but their polarity is opposite, since they are outside the coils. The extra needles which are mechanically connected together increase the sensitiveness of the instrument and form an astatic combination. The case carrying the small controlling magnet is shown at the side of the instrument. The large magnets at the back

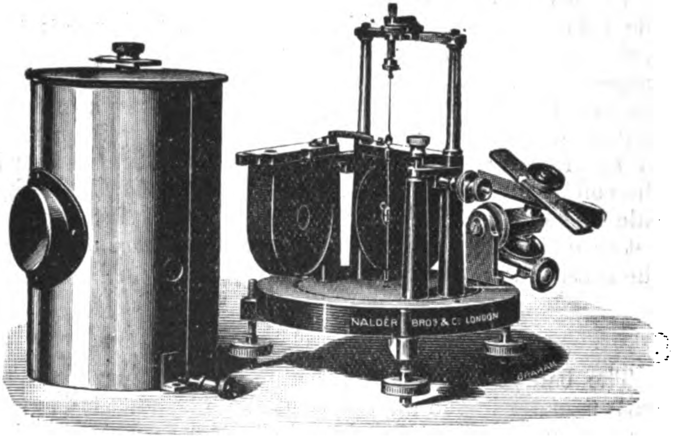

FIG. 46.—Ballistic galvanometer with the coils opened to show the needles.

are used for the purpose of bringing the needle to rest. instead of waiting until the vibration of the needle has died out after taking a reading. When the two magnets are placed one over the other, their effect upon the needle is *nil*, since they have opposite poles facing each other. Adjustment of their position is effected by the screws in connection with them.

Some galvanometers of the D'Arsonval type are used as ballistic galvanometers by replacing the light conducting frame upon which the coil is wound by an extra winding which can be short-circuited to damp the instrument, or which can be disconnected at will when required for ballistic tests. In the Ayrton Mather instrument the silver tube may be replaced by an ivory one with this object.

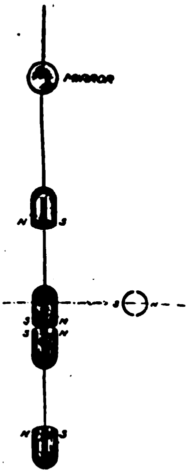

FIG. 47.—Needles and mirror of ballistic galvanometer.

FIGURES OF MERIT.

The figure of merit of a galvanometer is the value of the current required to produce a deflection of one division or one degree as the case may be. The smaller the figure of merit, the smaller is the minimum value of the current which the instrument will indicate. Sometimes the figure of merit is stated as the reciprocal of the current required to produce unit deflection, but this is not the practice of the Post Office. Yet another method of comparing the constants of galvanometers is to specify the value of the resistance in circuit with an E.M.F. of one volt to produce unit deflection. This is termed the "resistance constant," and is numerically identical with the value obtained for the figure of merit when defined as the reciprocal of the current required to produce unit deflection.

For the P.O. tangent galvanometer the figure of merit with standard adjustment is $\frac{1}{80}$ m.a., which is the current required to produce a deflection of one division. In the case of a reflecting galvanometer, the current required to produce a deflection of one millimetre from the scale zero when the scale is one metre distant from the mirror is usually taken as the figure of merit.

Where the deflections of an instrument do not bear any simple relation to the currents producing them, the deflection produced and the current required are stated.

The figures of merit of a few types of galvanometer are shown below:—

GALVANOMETERS FIGURES OF MERIT.

Type.	Resistance of coils.	Figure of merit.
Single current . . .	30ω	9·3 m.a. for deflection to stop-pin
Differential (one coil)	43ω	20 m.a. for deflection of 45°
Tangent	320ω	$\frac{1}{30}$ m.a. per division
Horizontal	800ω	·048 m.a. for 25°
Horizontal	12,500ω	·5 micro-ampere per division
Paul unipivot . . .	60ω	·6 micro-ampere per division
Single pivot reflecting	200ω	·04 micro-ampere per division
Paul reflecting (Ayrton Mather coil) .	1,400ω	·00862 micro-ampere per division
Kelvin	100,000ω	·0001 micro-ampere per division

NUMBER OF CONVOLUTIONS.

The sensitiveness of a tangent galvanometer is directly proportional to the number of turns of wire and inversely as the value of the earth's field and as the radius of the coil. Since the needle is one-tenth the diameter of the coil the diameter of the coil cannot be unduly reduced. The value of the earth's field may be regarded as constant at any one place, and the controlling magnet is employed for comparatively small adjustments. There still remains to be considered the number of turns or convolutions of wire. This may be made very large indeed, and an extremely small current may in this way be made to provide a comparatively strong magnetic field.

The magnetic field produced by a coil of wire is proportional to the current flowing in that coil multiplied by the number of turns of wire. Therefore one ampere flowing in one turn of wire will produce the same field as one milli-ampere flowing through 1000 turns of the same diameter.

In order to obtain a large number of turns of wire as near to the needle as possible, the wire should be fine. This means a considerable amount of resistance, and thus it is that the term "high-resistance galvanometer" has come to be synonymous with "galvanometer of high sensitivity." It is interesting to note that if a particular instrument is re-wound with wire of different gauge, its sensitiveness is directly proportional to the square root of its resistance (see page 70). For instance, if two galvanometers of equal dimensions each give 100 divisions deflection, and their resistances are respectively 900^{ω} and 9^{ω}, the currents indicated in the two cases will be as $\sqrt{9} : \sqrt{900}$, i.e. as 3 is to 30, or as 1 : 10. The 9^{ω} galvanometer's 100 divisions therefore represent ten times as much current as the 900^{ω} galvanometer giving the same deflection.

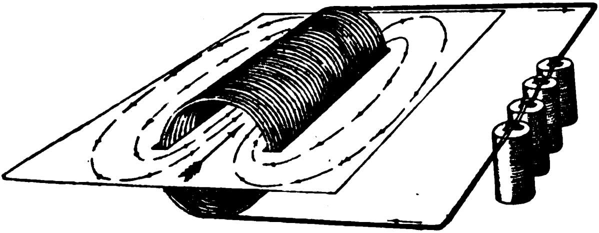

FIG. 48.—Illustrates magnetic field due to a coil of wire carrying a current.

SENSITIVENESS AND SENSITIVITY.

If the current flowing through a galvanometer produces a certain deflection and by altering the value of this current by an extremely small fraction of its value a comparatively large change in the deflection results, the galvanometer would be said to be highly sensitive. In comparing two instruments, the galvanometer which would produce the largest alteration in deflection corresponding to the minute fractional change of current value would be termed the more sensitive instrument. This is the strict meaning of the term, but it is often employed as a substitute for "sensitivity," *i.e.* "small figure of merit," or "large resistance constant."

GALVANOMETER SHUNTS.

The value of the current which can be measured by any particular galvanometer is distinctly limited. For instance, a Post Office tangent galvanometer will give a deflection of 200 divisions with a current of 2½ m.a. If it is desired to measure a larger current, two courses are open, either to re-wind the galvanometer with a proportionally smaller number of turns of wire, or to divert a large known portion of the current and to infer the value of the total current from a knowledge of the actual current shown upon the galvanometer and the proportion diverted. The former method has sometimes been employed and a plug switch provided by which any particular number of turns of wire could be joined up.

PRINCIPLE.

The method of diverting a known proportion of the current through another path placed in parallel with the galvanometer is termed "shunting the galvanometer," and the resistance employed is, in this connection, termed a "shunt." The arrangement is shown in Fig. 49, where the galvanometer, *G*, has a shunt, *S*, connected across its terminals The current entering the instrument divides between the galvanometer and the shunt in direct proportion to their conductances. If the resistances of the galvanometer and its shunt are

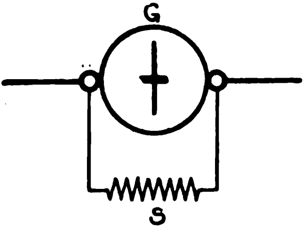

FIG. 49.—Shunted galvanometer.

equal, one half of the current flows through each path. The galvanometer therefore indicates ½ of the current flowing through the whole arrangement. The current indicated upon the galvanometer must therefore be multiplied by 2, and 2 is accordingly termed the multiplying power of the shunt. The shunt is termed a ½ shunt.

Let the resistance of the galvanometer under consideration be 90^{ω}, and then determine the consequences following the use of various shunt resistances. It has already been shown that if the shunt were 90^{ω} it would be termed a ½ shunt, and have a multiplying power of 2. If now the shunt were 45^{ω}, two-thirds of the total current would pass through the shunt and one-third through the galvanometer, therefore it would be a ⅓ shunt.

The following table gives the particulars of nine different shunts which might be applied to the 90^{ω} galvanometer, together with various facts derived therefrom:—

Resistance of galvanometer. (Ohms.)	Resistance of shunt. (Ohms.)	Proportion of the total current in the galvanometer.	Proportion of the total current in the shunt.	Name of shunt.	Multiplying power of shunt.
90	90	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	2
90	45	$\frac{1}{3}$	$\frac{2}{3}$	$\frac{1}{3}$	3
90	30	$\frac{1}{4}$	$\frac{3}{4}$	$\frac{1}{4}$	4
90	18	$\frac{1}{6}$	$\frac{5}{6}$	$\frac{1}{6}$	6
90	15	$\frac{1}{7}$	$\frac{6}{7}$	$\frac{1}{7}$	7
90	10	$\frac{1}{10}$	$\frac{9}{10}$	$\frac{1}{10}$	10
90	9	$\frac{1}{11}$	$\frac{10}{11}$	$\frac{1}{11}$	11
90	4½	$\frac{1}{21}$	$\frac{20}{21}$	$\frac{1}{21}$	21
90	2	$\frac{1}{46}$	$\frac{45}{46}$	$\frac{1}{46}$	46
90	1	$\frac{1}{91}$	$\frac{90}{91}$	$\frac{1}{91}$	91

The shunt takes its name from the fraction of the total current flowing through the galvanometer itself. If the 90^{ω} galvanometer unshunted gave a deflection of 20 divisions with 1·5 m.a. flowing through its coils, the value of 20 divisions with each of the shunts shown would be 1·5 m.a. multiplied by the multiplying power of the shunt, *e.g.* ½ shunt (1.5 × 2) m.a.; ⅓ shunt (1·5 × 3) m.a.; ¼ shunt (1·5 × 4) m.a., etc.

From a consideration of the numerical examples given for this particular galvanometer, it will be observed that the following relations hold :—

$$\text{Multiplying power} = \frac{\text{Galvo. res.} + \text{Shunt res.}}{\text{Shunt res.}} \quad . \quad . \quad (1)$$

$$\text{Shunt res.} = \frac{\text{Galvo. res.}}{\text{Multiplying power} - 1} \quad . \quad . \quad (2)$$

Rule I. states that the multiplying power of a shunt is equal to the sum of the resistances of the galvanometer and the shunt divided by the resistance of the shunt. In the case of the 10^{ω} shunt to the 90^{ω} galvanometer its multiplying power is at once found to be:—

$$\frac{90 + 10}{10} = 10.$$

The second rule enables the resistance of the shunt necessary to reduce the current through the galvanometer itself in any desired proportion to be ascertained. The shunt resistance required is equal to the galvanometer resistance divided by a number obtained by subtracting unity from the power of the shunt required. In the case of the 90^{ω} galvanometer, if it is desired to apply a $\frac{1}{6}$ shunt its resistances must be :—

$$\frac{90}{6 - 1} = 18^{\omega}.$$

Having established these rules, the following numerical examples of their application should be clear.

Example 1.—A galvanometer of 320^{ω} resistance having a constant of 80 divisions per milli-ampere is shunted by a resistance of $35\frac{5}{9}{}^{\omega}$. What is the power of the shunt, and what is the constant of the shunted instrument?

$$\text{From (1) multiplying power} = \frac{320 + 35\frac{5}{9}}{35\frac{5}{9}}$$
$$= 10$$
$$\text{Constant shunted} = \tfrac{1}{8} \text{ m.a. per division.}$$

Example 2.—What resistance must be applied to a 320^{ω} galvanometer in order to shunt it $\frac{1}{5}$, and what will be its constant if, when unshunted, 80 divisions represent 1 m.a.?

$$\text{From (2) shunt} = \frac{320}{5-1} = 80^{\omega}$$

Unshunted, 80 divisions = 1 m.a.
Shunted $\frac{1}{5}$, „ „ = 5 m.a.
or 16 „ = 1 m.a.

It will be obvious that the application of a shunt to a galvanometer reduces the resistance of the instrument as a whole. The resistance is then equal to the product of the resistances of the galvanometer and shunt divided by their sum. Fortunately a much simpler relation holds in the case of a galvanometer and shunt. It is—

$$\text{The combined resistance} = \frac{\text{Resistance of Galvanometer}}{\text{Multiplying power of shunt}} \quad (3)$$

For instance, the combined resistance of the 320^{ω} galvanometer and shunt dealt with in the last example will be, according to this rule, $\frac{320}{5} = 64^{\omega}$, a result which may readily be verified.

Compensating Resistance.

The reduction in the resistance of a circuit containing a galvanometer, due to the application of a shunt, leads to an increased value of current through that circuit. The application of the $\frac{1}{5}$ shunt, therefore, would not reduce the value of the current from, say, 200 divisions to 40 divisions. If the resistance of the circuit, exclusive of the galvanometer, were absolutely nil, the application of the shunt would not reduce the deflection at all. This fact led Kempe to design a special shunt box in which each shunt when applied also introduced a resistance in the main circuit equivalent to the decrease produced by its application. This resistance was termed a compensating resistance, and in the case of a 320^{ω} galvanometer with $\frac{1}{5}$ shunt would be $320 - \frac{320}{5} = 256^{\omega}$. The joint resistance added to the compensating resistance is, of course, 320^{ω}, so that the application of the shunt would not alter the resistance of the apparatus as a whole.

The device has not, however, found favour in practice for two reasons, firstly, its cost, and secondly, that in the majority of cases the resistance of the galvanometer or of the galvanometer and shunt is but a small fraction of the resistance of the circuit as a whole. In the few cases where this is not the case the calculation of the effect of the diminished resistance is comparatively simple. To take a practical case occurring in every-day telegraph work. The current flowing through a duplex circuit may be measured by inserting a tangent galvanometer at the test box whilst the keys are at rest. The $\frac{1}{10}$ shunt is applied which reduces the galvanometer resistance to 32^{ω} and a deflection of, say, 54 divisions is obtained. To be strictly accurate, the fact that the circuit resistance, say 1200^{ω}, has been increased by $2\frac{2}{3}\%$ owing to the introduction of the galvanometer should be allowed for in calculating the current in the circuit from the measurement. The value observed should be increased in the same percentage, but it should be noted that the circuit resistance in this case must include the batteries. In this instance the compensating resistance would be highly objectionable since the resistance introduced into the circuit would be 320^{ω} instead of 32^{ω}, and the increase in the circuit resistance would therefore amount to $26\frac{2}{3}\%$. If the current indicated under these circumstances were 20 m.a. the value of the current through the circuit working normally would be $25\frac{1}{3}$ m.a.

In measuring very high resistances the correction necessary is usually so small as to be negligible. This is the case with the testing set described on page 169.

Consideration of the table on page 92 shows that by the application of shunts the normal constant of $\frac{1}{80}$ m.a. per division may be raised to various values up to 4 m.a. per division. It may be added that, referring to Fig. 31, the highest shunt resistance (80^{ω}) is required for the $\frac{1}{2}$ shunt, and that this represents the sum of all the coils on the right. The actual resistance between the $\frac{1}{2}$ and $\frac{1}{10}$ block is therefore $44{\cdot}44^{\omega}$.

Shunts are very frequently employed in connection with reflecting galvanometers, and usually three values are supplied, viz. $\frac{1}{10}$, $\frac{1}{100}$, and $\frac{1}{1000}$. Unfortunately, many makers insist upon labelling these shunts with the fraction of the resistance of the galvanometer, *i. e.* $\frac{1}{9}$, $\frac{1}{99}$, and $\frac{1}{999}$. This fact occasionally leads to some confusion in the minds of students. Such a shunt box is illustrated in Fig. 50. The two terminals are connected to the galvanometer, and the particular shunts are introduced by placing the plug between the central block and the particular shunt required. At the back is placed a small movable switch which, upon being moved downwards, short-circuits the shunts altogether. The connections may be inferred from the detailed description of the tangent galvanometer shunts.

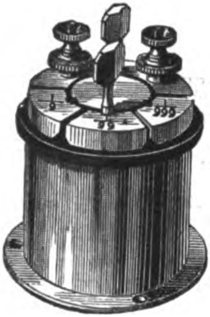

FIG. 50.—Galvanometer shunt box.

The following examples show a couple of problems which may arise in connection with shunts as applied to reflecting galvanometers.

Example 3.—A galvanometer of 950^{ω} resistance shunted $\frac{1}{10}$ gives a deflection of 53 divisions. What must be the resistance of the shunt applied to increase the deflection to 240 divisions?

Galvo. shunted $\frac{1}{10}$ gives 53 divisions.
∴ Galvo. unshunted gives 530 divisions.

Mult. Power of shunt to reduce 530 to 1 division = 530

∴ „ „ „ „ „ increase 1 div. to 240 divs. = $\frac{530}{240}$

$$\text{Shunt} = \frac{950}{\frac{530}{240} - 1} = \frac{950}{\frac{290}{240}} = 786{\cdot}2^{\omega}.$$

Example 4.—If the constant of a galvanometer of 800^{ω} resistance is ·002 m.a. per division, what will be its constant when shunted by a resistance of 55^{ω}?

$$\text{Multiplying power} = \frac{800 + 55}{55}$$

Unshunted. Value of 1 division $= \cdot 002$ m.a.

Shunted. „ „ „ $= \cdot 002 \times \frac{855}{55}$

$= \cdot 03109$ m.a. approx.

Universal Shunt.

The arrangement of shunts, previously considered, possesses the very great disadvantage that each set must be specially designed for the particular resistance of galvanometer with which it is to be used. This defect has been met by the invention of the universal shunt by Ayrton and Mather. This shunt may be applied to any galvanometer, irrespective of its resistance, and still give equally accurate results. On page 118 it was stated that:—

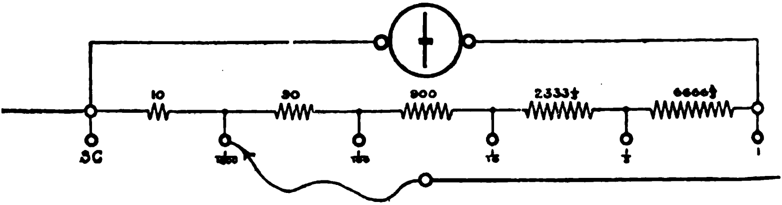

Fig. 51.—Principle of the universal shunt.

$$\text{Multiplying power} = \frac{\text{Galvo. resistance} + \text{Shunt res.}}{\text{Shunt res.}}.$$

If now the resistance of the galvanometer added to the shunt resistance could always have the same value, the multiplying power of the shunt would be inversely proportional to the resistance of the shunt.

In the universal shunt this object is attained by placing a subdivided resistance of 10,000$^{\omega}$ directly across the terminals of the galvanometer, and adding a radial contact arm moving over the series of studs in connection with those subdivisions. The arrangement is conventionally depicted in Fig. 51. When the arm is on the position marked 1 the galvanometer is shunted by $10{,}000^{\omega}$.

If the arm is moved to $\frac{1}{3}$ the resistance thrown into the circuit of the galvanometer is $6666{\cdot}7^{\omega}$, and across this is a resistance of $\frac{1}{3}$ of $10{,}000^{\omega} = 3333{\cdot}3^{\omega}$. Since the resistance of the galvanometer circuit and the resistance of the shunt proper is the same as in the first case (Galvo $+ 6666{\cdot}\dot{6}) + 3333{\cdot}\dot{3}$, the multiplying power is inversely proportional to the shunt resistance proper ($3333{\cdot}3^{\omega}$) and is therefore precisely three times that in the first case. It will be recognized that the value of the resistance of the Galvanometer + Shunt is the same for each position of the contact arm, and it therefore follows that:—

$$\text{Multiplying power} = \frac{\text{Total res. of box}}{\text{Res. of shunt}}\,{}^{*}.$$

A very little consideration of the figures given upon the sketch will show the truth of these facts. The practical form of the shunt box is shown in Fig. 52.

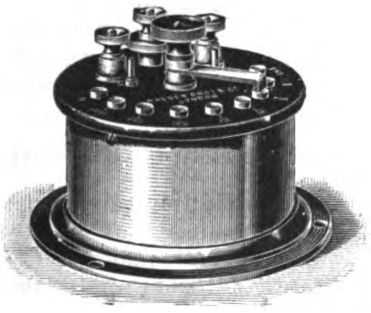

FIG. 52.—A universal shunt box.

Usually the total resistance of the box is either 1000^{ω}, $10{,}000^{\omega}$, or $100{,}000^{\omega}$, but it will be equally obvious that any value might be chosen. It is, however, advisable not to have too great a disparity between the resistance of the galvanometer and the total of the shunt box, as this leads to loss of sensitiveness.

---

* Let R = total resistance of shunt box
b = resistance of shunt
G = galvanometer resistance
C = current through galvanometer coils
C_1 = ,, ,, apparatus with shunt R^{ω}
C_2 = ,, ,, ,, ,, ,, b^{ω}

$C_1 = C\,\frac{R}{R+G}$ and $C_2 = C\,\frac{b}{R+G}$

$\therefore \frac{C_1}{C_2} = \frac{R}{b}$ or $C_1 = C_2\,\frac{R}{b}$;

that is, the multiplying power of the shunt is $\frac{R}{b}$.

A notable advantage gained by using the universal shunt is that the resistances required are mostly whole numbers, and where not so, the values are quite simple and readily obtained fractions. This is a remarkable advance upon the $\frac{1}{999}$ of 8576^{ω}, which would have to be calculated and provided for an instrument of 8576^{ω} shunted $\frac{1}{1000}$. The fact that the new shunts may be applied to any galvanometer without reference to, or knowledge of, its resistance cannot be too highly estimated.

The fact that the ordinary shunt coils are wound with german silver or manganin wire introduces a temperature error. This can be avoided by winding the coils with copper wire so that changes in temperature may affect equally both the shunt and the galvanometer coils. With the universal shunt this source of error does not arise since the shunt is independent of the galvanometer resistance. Compensating resistance boxes can only be used with ordinary individual shunts.

CONSTANT OF REFLECTING GALVANOMETER.

With a reflecting galvanometer the constant is taken in a similar manner, but usually considerable accuracy is required, and therefore a Clark cell is employed. A resistance of $10{,}000^{\omega}$ or $100{,}000^{\omega}$ is inserted with the cell and galvanometer. The galvanometer is usually heavily shunted.

As an example suppose that the Clark cell E.M.F. 1·433 volts (at the temperature at which the test is made) is joined to a 5000^{ω} galvanometer shunted $\frac{1}{100}$ through a resistance of $100{,}000^{\omega}$, and that a deflection of 200 divisions resulted—

Resistance of galvanometer and shunt =	50^{ω}
Standard cell about	50
Resistance coil 100,000 . . .	100,000
Total	100,100

$$\therefore \text{ total current} = \frac{1{\cdot}433}{100{,}100} = {\cdot}01432 \text{ m.a.}$$

Current through galvanometer = ·0001432 m.a.
Value of 1 division = ·000000716 m.a.

Reflecting galvanometers are, however, very frequently used in the same manner as the testing set described in Chapter V.

CHAPTER IV

THE MEASUREMENT OF E.M.F. AND BATTERY TESTING.

PART I.—VOLTMETERS.

IN order to measure the current flowing an ammeter or milli-amperemeter is interpolated in the circuit. It is therefore essential that the resistance of the instrument shall be small in comparison with the resistance of the circuit into which it is introduced. For, if this be not so, the ammeter resistance, which is added to circuit resistance, diminishes the value of the current, and the instrument does not therefore indicate the value of the original current.

If the resistance of a circuit is so high that the resistance added by including the resistance of the battery or other source of E.M.F. may be neglected, and the resistance therefore can be considered constant, the current produced in the circuit will depend upon and be directly proportional to the E.M.F. applied. A voltmeter is directly connected to the two points between which it is required to measure the E.M.F. or potential difference, and by similar reasoning to that employed to show that the resistance of an ammeter must be low, it will be recognized that a voltmeter must have a high resistance, since its connection across a circuit must not appreciably vary the resistance of, and consequently the difference of potential existing across, the circuit.

A voltmeter (unless on the electrostatic principle) may be defined as a high-resistance galvanometer or current-measuring device of unvarying constant with a scale marked in volts. For example, take a milli-amperemeter reading from 0 to 1 m.a. by gradations of $\frac{1}{100}$ m.a., and bring up its resistance to, say, 10,000 by adding a resistance coil in series with it. Then, since $C \times R = E$, a reading of 1 m.a. requires an E.M.F. of ·001 × 10,000 = 10^{v} to be applied to the instrument, and each division represents ·1 volt. To double the range of the instrument it is merely necessary to double its total resistance. Additional resistance coils used to increase the resistance of the instrument for extended range of measurement are termed multipliers.

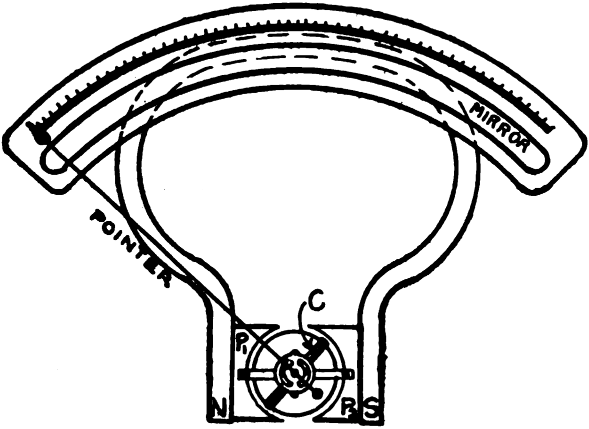

Fig. 53.—Weston voltmeter.

The Weston voltmeter (Fig. 53) consists of a D'Arsonval galvanometer with an aluminium pointer controlled by the moving coil and two flat spiral hair springs. These springs which provide the controlling force are of non-magnetic material and are placed in front and at the end of the pivoted moving coil, and serve also to connect the ends of the coil to the stationary terminals of the instrument. The scale is marked from 0 to 15 volts, but by using a resistance coil in series (*i.e.* a multiplier) the divisions read ten times these values, viz. from 0 to 150^{v}. The resistance of the instrument is $1677{\cdot}5^{\omega}$ for 15^{v}, and 16775^{ω} when reading to 150^{v}.

The resistance of the No. 2 Detector (see Fig. 37) when reading to 5^v is 500^ω, and a 4500^ω multiplier is added to extend the range to 50^v. Each scale division represents a current of ·2 m.a., and therefore with the resistance of the instrument at 500^ω is equivalent to $500 \times \cdot 0002 = \cdot 1^v$ and at 5000^ω to 1^v.

There are many other types of voltmeter in general use, but they may be classified as moving iron types, hot wire types, and electrostatic types. The moving iron types frequently are identical with the moving iron ammeter, but with a solenoid of fine wire to render the instrument sensitive and to increase its resistance. In the hot wire types, in which the current, by heating the wire, produces expansion of the wire or strip and so determines the motion of a pointer, a resistance coil is necessarily added to the instrument. The electrostatic instruments depend upon the attraction and repulsion between two charged vanes, one of which is movable. All these instruments may be used to measure alternating currents, whereas moving coil instruments cannot.*

PART II.—POTENTIOMETER MEASUREMENTS.

PRINCIPLE OF POTENTIOMETER.

The potentiometer method of measuring E.M.F.s is one of extreme accuracy and it is also a "null" or "zero" method, a term which signifies that the result of the test does not depend upon the observation of the value of a deflection, the galvanometer being used merely to *indicate* the existence or absence of a difference of potential and not to *measure* its value.

A long wire of uniform material and cross-section and of high resistivity is stretched above a scale of equal divisions between two terminals (Fig. 54). A contact point with a terminal attached to it slides over the wire and a secondary cell with an adjustable resistance sends a steady unvarying current through the slide wire, but this current must not be so large as to heat the wire appreciably. As the wire is of uniform resistance the potential due to the current flowing in the wire falls uniformly along it. For example, if the difference of potential between 0 and 1000 is $1{\cdot}5^{\mathrm{v}}$, the difference of potential between 0 and 500 is $\cdot75^{\mathrm{v}}$; in fact, each division represents $\frac{1\cdot5}{1000} = \cdot0015^{\mathrm{v}}$. The point marked 0 is termed the zero of the scale, and the potentials along the wire considered with respect to it.

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* Descriptions of a number of instruments of these various types will be found in Perren Maycock's *Electric Lighting and Power Distribution*, Vol. I. p. 361 *et seq.*

If now one end of a standard cell, with a galvanometer in series with it, be attached to the 0 end of the wire, whilst the other terminal is connected with the slider, a point can be found upon the slide wire where the difference of potential from 0 to that point is equal to the E.M.F. of the cell. Such a point is found by moving the slider until the galvanometer shows no deflection. When this is the case the difference of potential between 0 and the slider is equal to the E.M.F. of the cell. Since no current flows under these conditions the difference of potential between the negative pole of the cell and the opposite end of the galvanometer is clearly the same as that between the terminals of the cell. If this were not so, there would be a difference of potential between the terminals of the galvanometer. but this is not the case since there is no deflection.

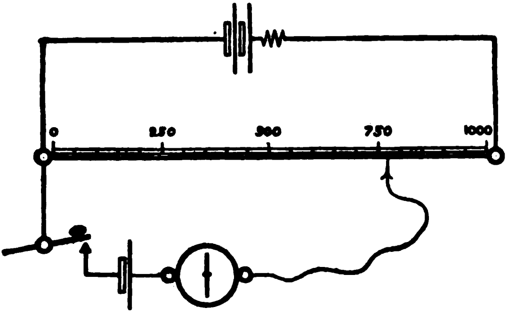

FIG. 54.—Potentiometer method of measuring the E.M.F. of a cell.

The difference of potential between 0 and the slider has now been determined, since it is known to be equal to the E.M.F. of the standard cell. Assume that the E.M.F. of the standard cell is 1·434 volts, and that the point at which the slider stands, for brevity usually termed the "reading," is 760 divisions. Therefore 760 divisions equal 1·434 volts, and one division will therefore be equal to $\frac{1}{760}$ of 1·434 volts. The standard cell is then removed and its place taken by the cell to be tested. The same procedure is followed, and a place is accordingly found where there is no deflection. Let this reading be 580 divisions. The difference of potential per division has already been found to be $\frac{1\cdot434}{760}$ volts, therefore 580 divisions represent 580 times as much. The E.M.F. of the cell is therefore—

$$580 \times \frac{1\cdot434}{760} = 1\cdot094 \text{ volts.}$$

The operation of finding the null point is very greatly simplified by the fact that the direction and magnitude of the deflection are determined by the distance of the slider from the point of balance. In the case cited the galvanometer would be deflected by the main battery overpowering the standard cell if the slider occupied a position to the right of the balance. This deflection would be largest at 1000, and would gradually reduce in value until it vanished at the null point, which in this case is 760. Upon the other side of the null point the standard cell would have a path along the slide wire, thus giving a reverse deflection, and the deflection would gradually increase until it reached a maximum at 0.

The accuracy of the method is only limited by the accuracy with which the slide-wire divisions can be read. This may greatly be increased by the use of a vernier. There are, however, two distinct assumptions made in the course of the tests, firstly that the current flowing along the slide wire is absolutely invariable, and secondly that the slide wire is absolutely uniform in resistance. The first assumption holds good if a secondary cell or cells are employed and the measurements are taken in rapid succession. The second one is not so readily met, the wire never is uniform, and, even if it were, it would very soon be damaged by continual use. This difficulty may be met by calibration, *i. e.* determining the resistance of the wire between a large number of points.

Consideration will show that the cell to be tested may be applied to the wire with a second slider, whilst the standard call is also connected. In this way, by watching both galvanometers it can be made quite certain that the value of the current through the slide wire is absolutely the same for both tests.

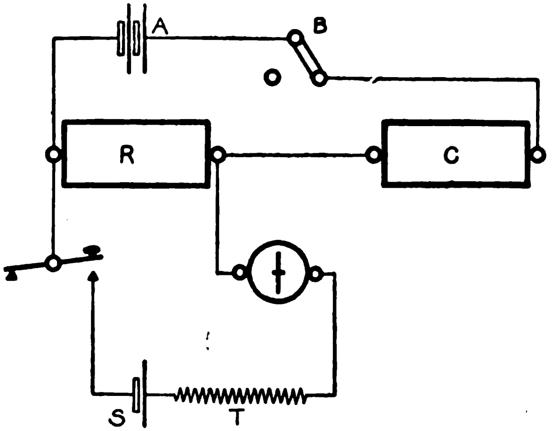

FIG. 55.—Rayleigh's compensation method of measuring the E.M.F. of a cell.

RAYLEIGH'S COMPENSATION METHOD.

In order to illustrate further the principle of the potentiometer it will be convenient to describe Rayleigh's compensation method of measuring E.M.F. Instead of a slide wire two boxes of coils, *R* and *C* (Fig. 55), each of which will give any integral value of resistance up to at least $10{,}000^{\omega}$, are connected together by a short piece of thick wire and a current from one or even two secondary cells is caused to flow through both in series. The resistance between the terminals of the battery is kept constant at 10,000$^{\omega}$, *i. e.* the resistance unplugged in *R* added to that of *C* is always kept equal to 10,000$^{\omega}$. When *R* is increased *C* is reduced by an exactly equal amount. The standard cell, together with a highly sensitive galvanometer, a large resistance coil *T*, and a suitable key, are connected to the ends of *R*. *R* is then adjusted until no deflection is shown upon the galvanometer when the key is depressed. With each increase of resistance in *R*, *C* is decreased by exactly the same amount, thus keeping the sum of *R* and *C* constant at 10,000$^{\omega}$. The difference of potential between the ends of *R* is equal to the E.M.F. of the standard cell. The value of *R* is noted and the cell to be tested is then substituted and *R* is readjusted until no deflection is obtained when the key is depressed. As in the previous test *R* and *C* together must be kept at 10,000$^{\omega}$ during the whole process.

The object of the coil *T*, which may have a resistance of from 100,000$^{\omega}$ to 200,000$^{\omega}$, is to prevent any large value of current from flowing through the galvanometer and cell owing to any accidental mistake.

A numerical example of the method is appended :—

The standard cell E.M.F. 1·434 volts balanced when *R* was 7352$^{\omega}$ and the cell under test when *R* was 6853$^{\omega}$. What is the E.M.F. of the cell tested ?

$$7352^{\omega} : 6853^{\omega} : : 1{\cdot}434 : \text{E.M.F.}$$

$$\therefore \text{E.M.F.} = \frac{6853 \times 1{\cdot}434}{7352} = 1{\cdot}3367 \text{ volts.}$$

It may be remarked that when *R* was 7352$^{\omega}$ *C* must have been $10{,}000 - 7352 = 2648^{\omega}$, and when 6853$^{\omega}$ *C* must have been 3147$^{\omega}$. The direction and magnitude of the deflection obtained when altering *R* serves as a guide in finding the required value.

THE CROMPTON POTENTIOMETER.

The arrangement of this instrument is shown diagrammatically in Fig 56. The slide wire *B C* is supplemented by fourteen coils *A B* called potentiometer coils, each of which is equal in resistance to one length of the slide wire. The constant resistance between its terminals is therefore equal to fifteen lengths of slide wire, and the arrangement corresponds to a slide wire fifteen times the length of the one provided and divided into 15,000 equal divisions. A radial contact arm moves over the junctions of the various coils, and this with the slider, which moves along the slide wire, form the two points between which the standard cell and galvanometer are joined. If the radial arm stood at 11, whilst the slider stood at 73·6 the reading would be 1173·6. A couple of rheostats are included in the circuit of the slide wire and coils in order to adjust the value of the current through them from the single storage cell employed. In this way the instrument may be read direct, and thus a large amount of time which would otherwise be spent in arithmetical calculations is saved. Suppose the E.M.F. of the standard cell is 1·434 volts. The radial arm is set at 14, whilst the slider is placed at 34·0, and by means of the rheostats mentioned the current is adjusted until no deflection is produced. When this is the case each coil represents $\frac{1}{10}$ volt and each

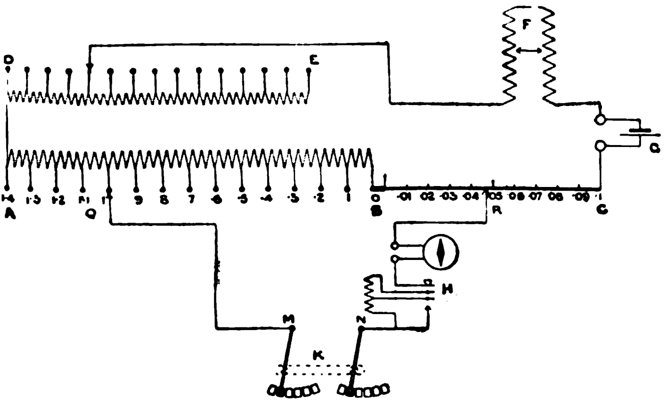

FIG. 56.—Theoretical connections of Crompton Potentiometer.

division $\frac{1}{1000}$ volt. The E.M.F. of any cell is then given as one thousandth of the reading obtained.

In the latest Crompton pattern (Fig. 57) the slide wire is placed within the instrument to avoid the risk of accidental damage. It will be observed that the first two figures of the result are obtained by resistance coils, and that the remainder only depend upon the slide wire.

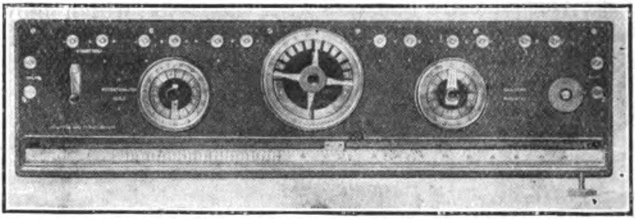

FIG. 57.—General appearance of Crompton Potentiometer.

Any current may be measured by measuring the difference of potential it produces across the ends of a known resistance, and standard resistances to take such huge currents as 2000 amperes have been designed for use in this way. Similarly high voltages may be measured by joining up to the *circuit* a series of 10,000$^{\omega}$ coils and measuring by the potentiometer the difference of potential across a subdivision of one of them. For example, to measure 1500 volts ten coils of 10,000$^{\omega}$ each would be joined across the source of E.M.F. One of these coils has a tap at 100$^{\omega}$, and across its ends the potential difference will be $\frac{1}{1000}$ of the total E.M.F., *i. e.* about 1·5 volts,

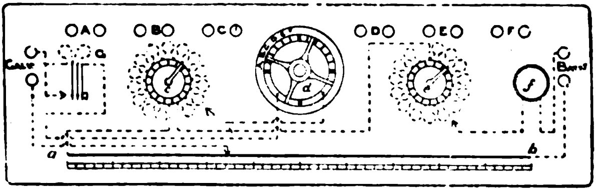

FIG. 58.—Connections of Crompton Potentiometer.

This difference is of the same order as the E.M.F. of the Clark cell, and it will therefore be recognized that its measurement can be carried out with the utmost accuracy.

There are other types of potentiometer, but the principle of all is the same. For example, Nalder Bros. have replaced the slide wire by a series of 100 equal resistance coils with a radial arm moving over their junctions. A second set of 150 coils, each equal to 100 times the resistance of each of the first set, is connected in series with the first set and a similar radial contact arm moving over the junctions of the 150 coils is provided. As in the Crompton form, an adjustable rheostat is provided to obtain direct readings in volts. The arrangement corresponds to a slide wire with 15,000 fixed contacts, and to measure high voltages a potential divider similar in principle to that already described is employed. The absence of a slide wire is distinctly desirable since it is obviously liable to injury, but at the same time it may be remarked that its presence gives superior fineness of adjustment.

The potentiometer is of almost limitless value in accurate electrical measurements, whilst the principles underlying its use are as simple as they are valuable. The methods described may, however, be carried out by means of a few sets of resistance coils or Wheatstone Bridges (as in the Rayleigh method of measuring E.M.F.).

PART III.—BATTERY TESTING.

MEASUREMENT OF E.M.F.

When the highest accuracy is required in measuring the E.M.F. of a cell either the potentiometer or Rayleigh's compensation method, both of which involve the use of a standard cell, is invariably employed. But for all ordinary purposes a voltmeter of high resistance with a suitable range of measurement, such as the Weston pattern described on page 127, may be used. It is then merely necessary to join up the cell to the voltmeter and read the E.M.F. in volts indicated by the pointer. With this instrument the E.M.F. of any battery having an E.M.F. of 150^v or less may be measured with a considerable degree of accuracy. The No. 2 Detector (page 101) may be used instead of the Weston voltmeter, but its general construction is more robust, its scale is less finely divided, and, whilst it does not give such accurate results as the Weston instrument its indications are quite sufficient for most practical purposes.

POST OFFICE STANDARD TEST.

The E.M.F. of any cell is higher immediately after a period of rest than the mean value during the time it is discharging a current. The extent to which the E.M.F. falls during the discharge is determined by the value of the current and the state of exhaustion of the depolarizer. As indicated on page 19, in the case of the simple cell the E.M.F. fell very rapidly. With Leclanché cells charged with granular manganese dioxide the fall in E.M.F. during the first few minutes is also very rapid unless the current rate is very low. Conversely, the rate of recovery of the same cell, during a period of rest, is rapid. Hence tests taken of the E.M.F. of a Leclanché cell should be so designed that regard is paid to the conditions under which the battery is to be applied. If it be applied for the purpose of ringing an ordinary bell for very brief periods with reasonably long intervals of rest the E.M.F. measured during periods of rest may be considered approximately the mean E.M.F. during a period of discharge. On the other hand, if the battery be applied for a continuous period of some length the value of the mean working E.M.F. will be very much less. A few examples quoted from the researches of J. G. Lucas will make this clear.

Two new granular Leclanché cells measured $3{\cdot}1^v$ when first placed upon a circuit arranged so that a current of 80 m.a. was flowing. Five minutes later the E.M.F. had fallen to $2{\cdot}7^v$, and at the end of 30 minutes the E.M.F. had fallen to $2{\cdot}5^v$; upon disconnecting the battery the E.M.F. rose in five minutes to $2{\cdot}75^v$, and at the end of 30 minutes it measured $2{\cdot}9^v$.

COMPARISON OF E.M.F.S OF GRANULAR AND POWDERED MnO_2 CELLS.

Conditions.	Granular MnO_2 cells E.M.F.	Powdered MnO_2 cells E.M.F.
E.M.F. when newly made up	3·1	3·05
,, after 5 minutes' discharge at 80 m.a. . .	2·7	2·95
,, ,, 30 minutes' discharge at 80 m a. . .	2·5	2·9
,, ,, 5 minutes' rest	2·75	—
,, ,, 30 minutes' rest	2·9	—
Both cells were then discharged until their E.M.F.s had fallen to one volt per cell.		
E.M.F. after 17 hours' rest	2·6	2·2
,, ,, 7 minutes' discharge at 70 m.a. . .	2·0	—
,, ,, 5 minutes' discharge at 70 m.a. . .	—	2·0
,, ,, 30 minutes' discharge at 70 m.a.. .	1·6	1·925
,, ,, 2 months' rest	2·9	—
,, ,, 7 minutes' discharge	2·3	—
,, ,, 30 minutes' discharge	1·85	—

The tests now applied by the Post Office for primary cells are first to measure the E.M.F. of a cell after a period of rest and then to shunt the battery by a resistance of two ohms per cell for one minute and, after removing the shunt, immediately to note the value that the E.M.F. has fallen to. The cell is rejected if the latter value is below 1·8^{v} for Bichromate and 1^{v} for Leclanché cells (see also Voltmeter shunt method, page 141).

DIRECT DEFLECTION METHOD.

The E.M.F. of a cell may be measured with the aid of a P.O. tangent galvanometer and a sealed standard cell, but the result of the test, whilst somewhat more accurate than a measurement with the No. 2 Detector, is usually less accurate than a Weston voltmeter measurement. In a circuit having a resistance of 800$^{\omega}$ an E.M.F. of 1^{v} will produce a current of $1\frac{1}{4}$ m.a. which on a P.O. tangent galvanometer adjusted to standard sensitiveness produces a deflection of 100 divisions. It may be assumed that the internal resistance of the cell to be tested is 3$^{\omega}$, and it will later be shown that if the actual resistance is either higher or lower than this average amount no serious error in the result of the test will be made.

The method of test is as follows:—

(i) The sealed standard cell is joined up and the galvanometer adjusted to the deflection shown on the box.

(ii) The standard cell is removed and the cell to be tested is joined up with a resistance of 477ω in series with the galvanometer and the deflection noted.

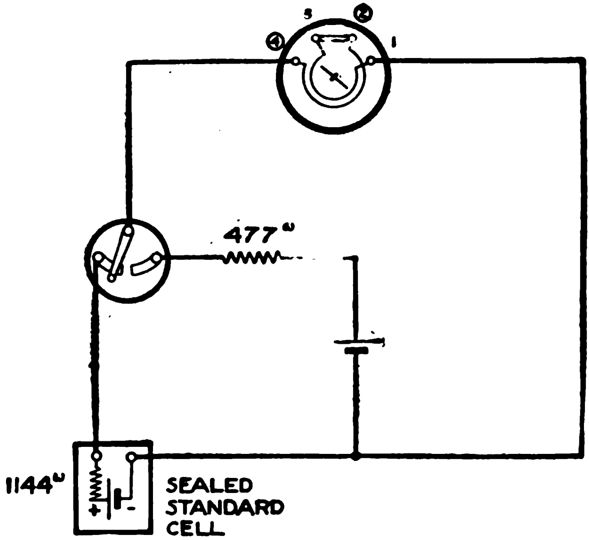

FIG. 59.—Use of sealed standard cell

The E.M.F. in volts of the cell tested is equal to the deflection in divisions divided by 100, *e. g.* if the cell under test gave a deflection of 172 divisions its E.M.F. is 1·72ᵛ.

The resistance of the circuit exclusive of the cell under test is 797ω, and therefore the total resistance of the circuit would vary from 797ω with a cell of negligible resistance to 807^{ω} with a cell having a resistance of 10^{ω}, and the error in assuming the total resistance to be 800^{ω} does not quite amount to 1 °/₀ in either case, and this represents the accuracy of the test since the deflection can be read to about one half of 1 °/₀.

This method is a modification of what is generally termed the direct deflection method of measuring E.M.F. With a Clark cell and a reflecting galvanometer the E.M.F. of a cell may be measured by taking the relative deflections produced through a high resistance with the galvanometer heavily shunted to reduce its sensitiveness thus—

(i) Join up the Clark cell (E.M.F. $1{\cdot}434^{v}$) with a resistance of $10{,}000^{\omega}$ and a reflecting galvanometer shunted $\frac{1}{1000}$ and note the deflection.

(ii) Substitute the cell to be tested for the Clark cell and again observe the deflection.

Then the E.M.F.s of the cells are proportional to the deflections which they produce, *e.g.* if the Clark cell gave 478 divisions and the cell tested 600 divisions its E.M.F. is—

$$\frac{1{\cdot}434 \times 600}{478} = 1{\cdot}8^{v}$$

In general it may be said that the E.M.F.'s of two cells may be compared by comparing the deflections produced upon any high resistance galvanometer in which there is a definite known relation between the deflection and the current producing it.

In carrying out any of these tests it is convenient and advisable to place a key or two-way switch in circuit.

EQUAL CURRENT METHOD.

The E.M.F. of a large battery may be measured with the aid of a P.O. tangent galvanometer, sealed standard cell and a rheostat by a simple modification of the equal current method. The equal current method depends upon the fact that if two circuits carry an equal current, the E.M.F.s producing those currents are in direct proportion to the respective total resistances of the circuits. For example, if the resistances of the two circuits were 2000ω and 1000ω respectively it would require twice the E.M.F. to furnish the same current in the first circuit as would be required in the second.

The method is carried out thus—

(i) The sealed standard cell is joined up to the rheostat (with no resistance inserted), P.O. tangent galvanometer, and single current key (Fig. 60) and the galvanometer adjusted to the deflection marked on the box.

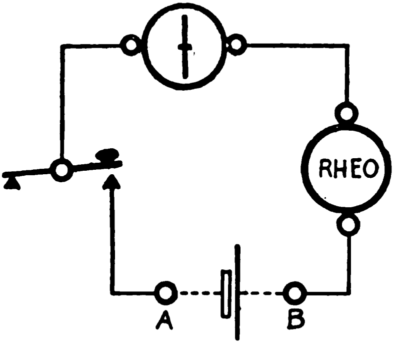

FIG. 60.—Equal current method of measuring the E.M.F. of a battery.

(ii) The cell to be tested is substituted for the standard cell (between *A* and *B*, Fig. 60) and a large value of resistance inserted in the rheostat before depressing the key. The resistance is then adjusted until the deflection is 80 divisions (*i. e.* 1 m.a.).

Then the E.M.F. of the battery in volts is equal to one thousandth of the *total* resistance of the circuit in the second case. In this case the resistances are so high that the battery resistance may be neglected. If, in testing a 20-cell battery the total of the rheostats stood at 24,620ω with the 320ω of the galvanometer, the E.M.F. of the battery is $\frac{1}{1000}$ of $(24{,}620 + 320) = 25^{v}$ approximately. These resistances are inconveniently high and a single rheostat giving a total resistance up to 8430ω will suffice if shunts be used. For example, with the rheostat at 4876ω and the galvanometer shunted $\frac{1}{5}$ (resistance 64ω) with 20 cells their E.M.F. is found as before, but the result is multiplied by the power of the shunt used—

$$\tfrac{1}{1000} \text{ of } (4876^{\omega} + 64 + 60) \times 5 = 25^{v}$$

In this instance an allowance of 3^{ω} per cell has been made to cover the internal resistance of the battery.

With the $\frac{1}{20}$ shunt a battery having an E.M.F. of over 160^{v} could be measured with the aid of a single rheostat.

In making the tests the most accurate results are obtained by making the rheostat resistance as high and the shunt as low as possible. For example, in the case of the 25^{v} battery a rheostat resistance of only 557^{ω} would be needed if the $\frac{1}{40}$ shunt were used—

$$\tfrac{1}{1000} \text{ of } (557 + 8 + 60) \times 40 = 25^{v}.$$

By making the resistance high the assumption that the internal resistance per cell is 3^{ω} does not involve any serious error.

The principle of the test may be summed up by saying that the resistance of the external circuit is made large in comparison with the internal resistance of the cells under test, so that no serious error is made in assuming the total resistance to be that of the external circuit plus the internal resistance taken at 3^{ω} per cell. The E.M.F. in the circuit is then the total resistance multiplied by the current in amperes. For example, 80 divisions with the $\frac{1}{8}$ shunt = ·005 ampere, and with a total resistance of $(4876 + 64 + 60) = 5000^{\omega}$, $E = 5000 \times \cdot 005 = 25^{v}$.

THE MEASUREMENT OF INTERNAL RESISTANCE.

VOLTMETER SHUNT METHOD.

The internal resistance of a cell or battery can readily be ascertained by measuring, with a voltmeter, (i) the E.M.F. of the cell or battery, and (ii) the difference of potential across its terminals when joined by a low resistance of known value (*vide* page 55). These measurements may be effected with reasonable accuracy with the aid of a No. 2 Detector.

Calling E the E.M.F. of the battery, V the difference of potential across its terminals when joined by a resistance of S ohms, the internal resistance r is—

$$r = S \times \frac{E - V}{V}$$

Example.—The open circuit E.M F. of a battery is measured as 28^{v}. When its terminals are joined by a resistance of 40^{ω} the difference of potential is 20^{v}. What is its internal resistance?

$$r = 40 \times \frac{28 - 20}{20} = 16^{\omega}.$$

Here it will be well to point out that, in order to avoid errors in the result of the test due to polarization, the potential difference across the shunt should be observed as quickly as possible after the shunt is applied.

After the shunt has been applied for a period of one minute the potential difference should again be taken. If this is less than 1 for Leclanché and $1{\cdot}8^{\text{v}}$ for Bichromate cells the depolarization is inefficient and new MnO_2 or Chromic salts respectively are required. This test is valuable since a cell tested rapidly may indicate satisfactory E.M.F. and internal resistance, and yet, owing to the depolarizing agent being practically exhausted, would be unsatisfactory in actual service.

HALF-DEFLECTION METHOD.

The "half-deflection" method of measuring the internal resistance of a cell or battery is one of the simplest and easiest tests to carry out. The only apparatus required is a tangent or a reflecting galvanometer and a set of resistance coils.

The principle of the method may be stated as follows:—If the *current* through a circuit, due to a constant E.M.F., is *halved*, then the *resistance* of that circuit must have been *doubled*. For instance, 20 volts applied to a circuit having a total resistance of 1000^{ω} produces a current of 20 m.a. Now the resistance of the circuit must clearly be doubled in order to reduce the current to half its former value, viz. to 10 m.a. Firstly, it will be well to consider the simplest case in which the resistance of the galvanometer is far less than the internal resistance of the battery and in which the battery connected to the galvanometer gives a convenient deflection without the aid of added resistance.

The cell or battery to be tested is joined up in series with the galvanometer, a key, and a set of resistance coils. No resistance is inserted in the resistance box, and, upon completion of the circuit, a large and easily read deflection is obtained. This deflection is then reduced to half its former value by introducing resistance into the circuit by means of the set of coils. When this has been done the resistance unplugged is equal to the internal resistance of the battery or cell. This is obviously so since the total resistance of the circuit was at first equal to the internal resistance of the battery or cell tested (galvanometer resistance and resistance box assumed to be negligible). In the second case the resistance unplugged doubled the resistance of the circuit, therefore this amount must be equal to the resistance of the circuit before it was inserted.

The conditions here laid down are readily fulfilled by a reflecting galvanometer shunted by a few inches of No. 20 copper wire. This sufficiently reduces the sensitiveness of the galvanometer and at the same time renders its resistance quite negligible.

It is obviously essential that a small change of resistance in the rheostat shall produce as large a change in the deflection as possible if an accurate result is to be obtained. If the external resistance of the circuit has a high value it serves to swamp the internal resistance of the battery, and the conditions are then analagous to those which would result when attempting to weigh a single brick on a 5 cwt. weighing machine.

The next case to be considered is where the resistance of the galvanometer cannot be neglected and where resistance has to be added to the circuit to obtain a satisfactory deflection. These values are noted, and the resistance raised until the deflection in tangent divisions is halved. In this case the resistance of the circuit has obviously been doubled since the current through the circuit is reduced to one-half. Now the *added* resistance is therefore equal to the resistance of the circuit before its addition, *i. e.* it is equal to the internal resistance of the battery, the resistance of the galvanometer and the resistance inserted in the rheostat for the first test, added together.

Example.—The P.O. tangent galvanometer shunted $\frac{1}{10}$th is joined up with 40^{ω} in the rheostat and a deflection of 180 divisions is produced. This is reduced to 90 divisions by raising the resistance in the box to 150^{ω}.

What is the internal resistance of the battery?

Resistance added in box $= 150 - 40 = 110^{\omega}$.

Added resistance = Battery + Galvo. + Res. in box for 1st test.

$$i.e.\ 110 = \text{Battery} + 8 + 40$$
$$110 = \text{Battery} + 48$$
$$\therefore \text{Internal resistance} = 110 - 48 = 62^{\omega}.$$

The rule for finding the internal resistance from the above data has been designedly omitted, since it is usually memorized to the obscurement of the very simple and useful principles involved in the test.

The best conditions for the accuracy of the result of the half-deflection method are when the resistance of the external circuit in the first test is as small as possible, compared with the internal resistance of the battery to be tested.

DIMINISHED DEFLECTION DIRECT METHOD.

This method is an extension of the half-deflection method. In practice it is often inconvenient to halve a deflection exactly; for instance, in measuring the resistance of a single cell one may not happen to have resistance coils arranged in sufficiently small fractions of an ohm to reduce the deflection to exactly one-half. The connections are precisely as in the half-deflection method. The resistance in the rheostat is adjusted until a convenient deflection is obtained, and this resistance is then raised until the deflection is materially reduced, preferably to about one *third* of its former value. Then—

$$\text{Internal resistance} = \frac{d_2 R_2 - d_1 R_1}{d_1 - d_2} - G$$

where d_1 is the deflection obtained with R_1 ohms in the rheostat through a galvanometer of G ohms resistance and

d_2 is the deflection given when the resistance in the box has been raised to R_2 ohms.

Example.—Eighty-five divisions are obtained with 20^ω in the resistance box through a galvanometer of 15^ω resistance, and 30 divisions are obtained when the resistance in the box is raised to 300^ω. What is the internal resistance of the battery?

$$\text{Internal resistance} = \frac{30 \times 300 - 85 \times 20}{85 - 30} - 15$$
$$= 117{\cdot}7^\omega \text{ approx.}$$

The best conditions for this test are when the smaller

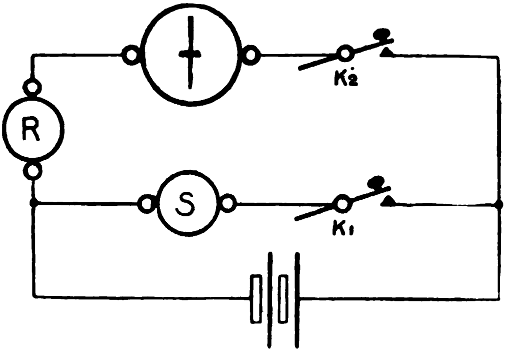

FIG. 61.—Thomson's method of measuring the internal resistance of a battery

deflection is exactly one-third of the larger, and when the galvanometer resistance and the resistance first unplugged in the box are as low as possible.

THOMSON METHOD.

The Thomson method consists in obtaining equal deflections upon a galvanometer, firstly with a resistance connected across its terminals, and secondly with resistance inserted in series with the battery and galvanometer. The test may be carried out with a couple of rheostats and two keys (Fig. 61), or with a Wheatstone Bridge.

The keys K_1 and K_2 are closed and the resistance in S is adjusted until a deflection, as near the angle of maximum sensitiveness as possible, is obtained whilst R stands at 0. The deflection is then reproduced by adding resistance in R until exactly the same deflection as before is obtained. For this purpose only K_2 is closed. When this has been done the resistance of the battery is equal to the product of the resistances employed at R and S divided by the resistance of the galvanometer.

In practice there is a great deal of risk in employing this method, since the accuracy of the test depends to a remarkable degree upon the observance of the best conditions. The shunt resistance should be less than the internal resistance of the battery, and R should be as large as possible. Assuming that the galvanometer deflection can be read to 1 $^{\circ}/_{\circ}$, the degree of accuracy obtainable is approximately 1 $^{\circ}/_{\circ}$, with the following values:—

Galvanometer resistance, 250^{ω}, shunt 10^{ω}, and R_1 5000^{ω}.

$$\text{Internal resistance} = \frac{5000 \times 10}{250} = 200^{\omega}.$$

Had S been 100^{ω} the error might have amounted to 2 $^{\circ}/_{\circ}$.

The usual arrangement of this test is slightly more complex than the one given above. Resistance is inserted in R when the deflection is obtained with S across the poles of the battery. The key K_1 is opened and R is again adjusted until the same deflection is produced. When this is the case the resistance of the battery:—

$$r = S\,\frac{R_2 - R_1}{R_1 + G}.$$

As previously remarked, S should be less than the battery resistance and R_2 should be as large as possible, R_1 added to the galvanometer resistance should be a slightly smaller proportion to the sum of $G + R_2$ than that of S to G. The following example indicates the necessary relative values:—

$$R_1 = 350^{\omega},\ R_2 = 6{,}200^{\omega},\ S = 20^{\omega},\ G = 200^{\omega}$$

$$r = 20 \times \frac{6200 - 350}{350 + 200}$$

$$= 212{\cdot}7^{\omega}.$$

When $R_1 = 0$ the formula becomes—

$$r = S\frac{R_2}{G}.$$

By making S equal to the galvanometer resistance r becomes equal to R_2 simply. It is, however, most undesirable to do this, as serious errors result from the departure from the best conditions which the simplification of the formula entails.

The Thomson method, above all others, needs great rapidity of measurement to avoid polarization troubles. The shunt resistance is always low as compared with the resistance of the battery, and heavy currents therefore result.

WHEATSTONE BRIDGE METHOD.

Another method of measuring the internal resistance of a battery is to divide it into two halves and join these two halves up so that their E.M.F.s oppose. The battery is then joined up to a Wheatstone Bridge in the ordinary way and measured like a simple resistance, but both directions of current must be employed. The resistance of the battery is then equal to the square root of the product of the resistances required to balance in the two cases. The method is one of considerable accuracy.

MUIRHEAD'S METHOD.

This method, invented by Kempe and slightly modified by Dr. Muirhead, is one of the best which has yet been devised, since by very slight alterations the E.M.F. and internal resistance of a battery may be measured whilst the latter is actually working.

A condenser and preferably a ballistic galvanometer are joined up with a shunt resistance (S), two keys, and the battery to be tested, as indicated in Fig. 62. Firstly, K_2 is depressed, thus producing a throw (d_1) upon the galvanometer. This is noted and, still holding K_2 down, K_1 is also depressed, resulting in a throw (d_2) in the opposite direction. The internal resistance of the battery is then

$$r = S\frac{d_2}{d_1 - d_2}.$$

In practice d_1 should be approximately three times d_2, in order to obtain the maximum amount of accuracy.

The theory of the test is fortunately very simple. When K_2 is depressed the condenser is given a charge proportional to the E.M.F. of the battery. This charge passes through the galvanometer and produces a deflection proportional to its magnitude. The depression of K_1 reduces the potential between the ends of the cell and hence between the ends of the condenser. The condenser partially discharges, the value of the discharge being directly proportional to the reduction in the potential difference across its terminals, which latter is equal to that lost in the cell itself.

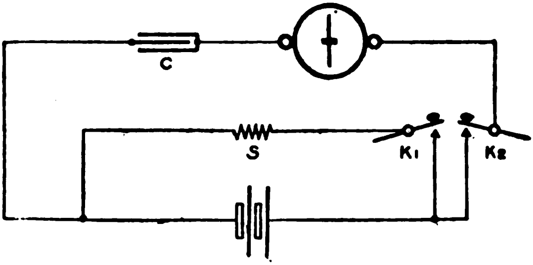

FIG. 62.—Muirhead's method of measuring the internal resistance of a battery.

A numerical example will perhaps best serve to make this clear:—

A deflection of 300 divisions was obtained upon depressing K_2 and 100 in the reverse direction when K_1 also was depressed. If S was 20^ω, what is the resistance of the battery?

$$r = 20 \times \frac{100}{300 - 100} = 10^\omega.$$

Inspection shows that this result is correct, but its accuracy may be checked by means of the principles proved on page 55.

RESISTANCE OF SECONDARY CELLS.

The resistance of a secondary cell or battery cannot conveniently be measured by any of the methods just described, owing to the extremely small resistance and very large currents to be dealt with. A fairly accurate test may, however, be made with the aid of a voltmeter and an ammeter. The battery is connected through the ammeter to a discharge tank, the resistance of which is adjusted until a current equal to maximum rate of discharge is obtained. The P.D. across the terminals of the battery is then taken, and, leaving the voltmeter connected the external circuit is broken and the voltmeter again read.

Example.—A voltmeter connected across the terminals of a secondary battery indicated 22·6 volts when the current passing was 150 amperes and 23·1 upon open circuit. What is the internal resistance of the battery ?

$$\text{E.M.F. lost in battery} = 23{\cdot}1 - 22{\cdot}6 = {\cdot}5^{v}$$

$$R = \frac{E}{C} \therefore \text{Internal res} = \frac{{\cdot}5}{150} = {\cdot}0033^{\omega}$$

ROUGH TESTS WITH Q AND I DETECTOR.

The 100^{ω} coil is used as a voltmeter and serves as an index to the E.M.F. of a cell, the readings indicating very clearly any differences between the E.M.F. of the various cells forming a battery. Similarly, the $\cdot 2^{\omega}$ coil may be used roughly to gauge the internal resistance. Each cell of a battery should, if in good condition, give approximately the same deflection as that given by the whole battery when connected to the $\cdot 2^{\omega}$ coil. This rough test was probably more extensively used than any other.

A most important test is made by observing for one or two minutes whether the deflection falls seriously when connected to the $\cdot 2^{\omega}$ coil. This test serves to show whether the depolarization is efficient.

BATTERY TESTING WITH DETECTOR NO. 2.

In order to simplify these tests a set of resistance coils with a connection key termed a "Coil Testing No. 1" has been introduced. This contains six coils having resistances of 2^{ω}, 2^{ω}, 6^{ω}, 10^{ω}, 20^{ω}, and 4960^{ω}. The terminal I and the terminal providing a resistance of 2^{ω} per cell are joined across the battery to be tested with the 5^{v} or 50^{v} coil of the detector as required. Three voltage readings are then taken as follows :—

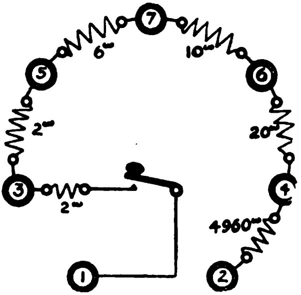

Fig. 62A.—Coil testing No 1.

(i) The voltage indicated on joining up the detector.

(ii) The testing coil key is depressed and the voltage read immediately.

(iii) The testing coil key is kept depressed for one minute and the voltage read immediately the key is released.

If the voltage reading (iii) is less than 1^{v} per cell for Leclanché or dry cells, or if the voltage reading (ii) is less than half of voltage reading (i) for Leclanché 0 or No. 1 cells, or less than voltage reading (i) divided by three for Leclanché No. 2A cells, then each cell should be tested separately.

For this purpose the 2^{ω} coil and 5^{v} winding of the detector should be used, and the three voltage readings taken as previously described. If voltage reading (iii) is less than 1^{v} the depolarizer needs renewal. If voltage reading (iii) is above 1^{v} and reading (ii) is less than $\frac{1}{2}$ or $\frac{1}{3}$ of reading (i) the excitant should be renewed and the cell cleaned out.

EDEN BATTERY TESTING INSTRUMENTS.

An exhaustive description of these instruments was given in both the previous editions of this work, but owing to the introduction of secondary cells at all the larger offices the instruments are not now in general use. It may be added that where a large number of Bichromate, Daniell, and Leclanché batteries need to be tested periodically the instruments are unrivalled in the rapidity with which the measurements can be made and in the simplicity of manipulation.

CHAPTER V

THE MEASUREMENT OF RESISTANCE.

PART I.—THE WHEATSTONE BRIDGE.

A Wheatstone Bridge comprises three sets of resistance coils, a battery and a galvanometer. With this apparatus the resistance of any line, instrument, or other system of conductors can readily be measured. The three resistances are usually included in a single box and the term Wheatstone Bridge is employed to denote only the box of coils. The apparatus is joined up as shown in Fig. 63, the resistance x to be measured being connected between A and D. The three resistances $C\,A$, $C\,B$ and $B\,D$ are then varied until the galvanometer is undeflected with K_2 and K_1, closed when the resistance

$$CB : BD :: CA : AD.$$

THEORY OF THE WHEATSTONE BRIDGE.

$C\,A\,D$ and $C_1\,B\,D_1$ are two wires whose resistances are represented by their respective lengths. Their extremities are joined by two heavy conductors $C\,C_1$ and $D\,D_1$ of negligible resistance, to which a battery is connected to maintain a constant difference of potential between the ends of the wires. Taking $C\,C_1$, which is connected to the negative pole of the battery as zero potential, the potential at D and D_1 is represented by $D\,V_1$ and $D_1 V_1{}^1$ and the fall of potential along the two wires by $V_1\ V_2\ C$ and $V_1{}^1\ V_2{}^1\ C_1$. Take any point A on $C\,D$. The potential will have fallen from $D\,V_1$ to $A\,V_2$ at this point. If on $C_1\,D_1$ a point B is found where the potential has fallen to $B V^1_2$ equal to $A V_2$, then the relative position of A along $C D$ is similar to the relative position of B along $C_1 D_1$, *i. e.* the resistances

$$C_1 B : B D_1 :: C A : A D.$$

The point B along $C_1 D_1$ is found by connecting a galvanometer to A and moving B until equality of potentials is indicated by the absence of deflection.

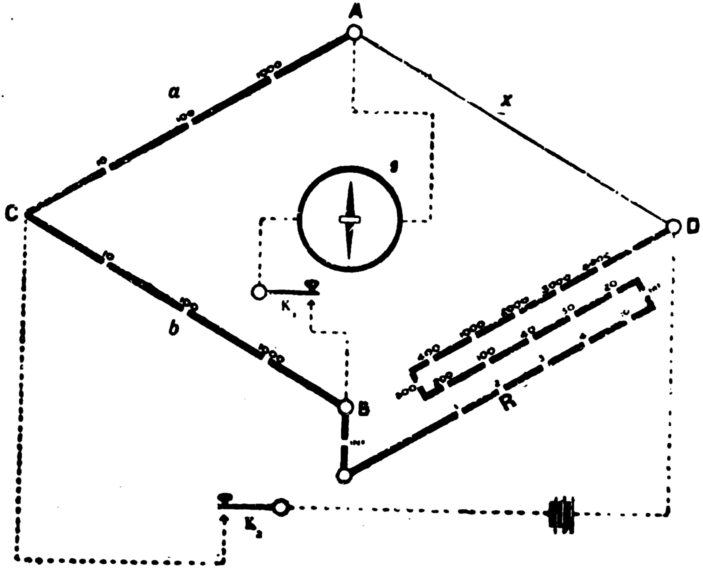

FIG. 63.—Arrangement of Wheatstone Bridge.

THE P.O. FORM OF WHEATSTONE BRIDGE.

The four resistances $C B$, $B D$, $C A$ and $A D$ in Figure 63 are respectively arranged in the same way as $C_1 B_1$ $B D_1$, $C A$ and $A D$, and when the galvanometer connected between A and B is undeflected (K_2 and K_1 being closed) the resistances

$$C B : B D : C A : A D,$$

or, using the single letters to denote the four resistances (Fig. 63).

$$b : R :: a : x, \text{ i. e. } a \times R = b \times x \text{ (i)}$$

$$\text{or } x = \frac{a}{b} \times R.$$

The resistances a and b, termed the proportionals or ratio arms, usually each consist of three coils 10^{ω}, 100^{ω}, and 1000^{ω}. The third, or rheostat, arm contains 16 coils, by means of which resistance from 1^{ω} to $11{,}110^{\omega}$ by gradations of 1^{ω} may be inserted.

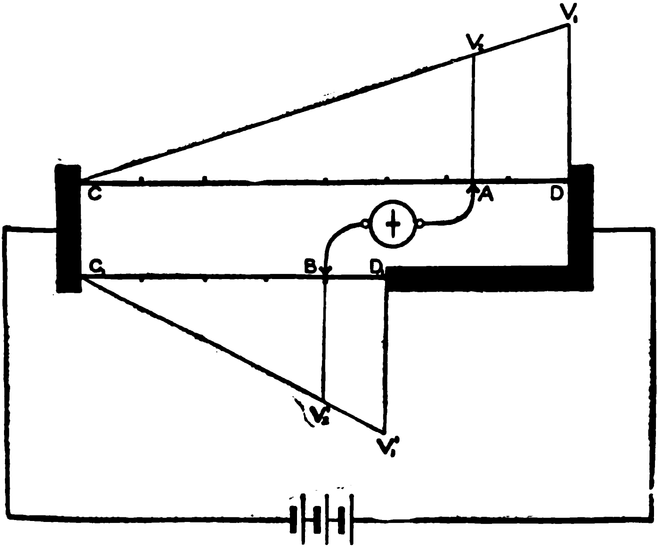

Fig. 64.—Principle of Wheatstone Bridge.

If a and b are given equal values the resistance in R is equal to the unknown resistance x. With $a = 1000$ and $b = 10^{\omega}$ the unknown resistance x is 100 times that of R, and the highest resistance which such a bridge can measure is therefore $100 \times 11{,}110^{\omega} = 1{\cdot}111$ megohms. The ratio of a to b may be made 1, 10, 100, $\frac{1}{10}$, or $\frac{1}{100}$, thus theoretically providing for the measurement of any resistance from $\frac{1}{100}$ω to 1·111 megohms. Since all these ratios are multiples or sub-multiples of 10 the value of any resistance tested may be written down without calculation. For instance, if *a* is 100, *b* is 1000, and *R* is 1536, when a balance is obtained the resistance tested is 153·6ω.

The direction of the deflection on the galvanometer at once indicates whether the resistance inserted in *R* is greater or less than that required to produce a balance.

The actual arrangement of the *P O.* pattern is shown in

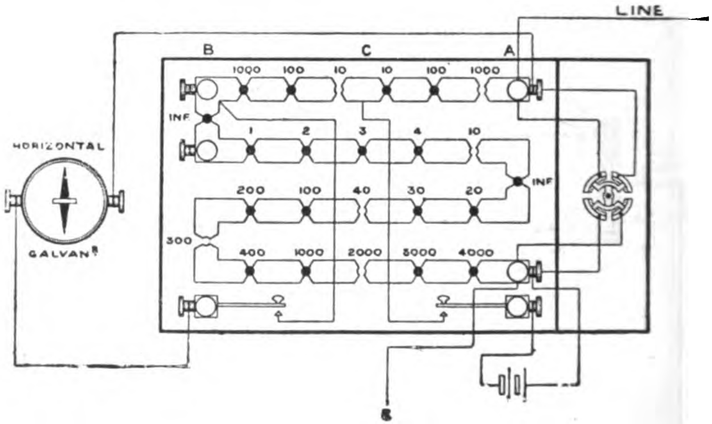

FIG. 65.—Actual arrangement of a Wheatstone Bridge of the P.O. pattern.

Fig. 65, the ratio arms *B C* and *C A* being lettered to correspond with Fig. 63. It is often required to reverse the direction of the testing current through the resistance to be measured (*vide* page 740), and this is effected by turning the handle of the reversing switch on the side of the box (compare Figs. 66 and 67). The ends of the ratio arm *C A* and the rheostat arm are connected to double terminals (Fig. 66), the upper and lower binding screws being insulated from each other by a flanged ebonite tube. With the handle in the position shown in Fig. 65 the *A* is joined through to the upper part of the terminal through the upper pair of connected brass quadrants, and *R* is similarly connected to the upper terminal above *R*. By turning the handle through 90 degrees *A* is joined to the upper part of *R* and *R* to the upper part of *A*. This arrangement is preferable to reversing the battery, since the reversal of the switch does not alter the meaning of the direction in which the needle deflects. A deflection to the right, say, still means that too much resistance has been inserted, whereas on the reversal of the battery itself it would mean that too little resistance had been inserted,

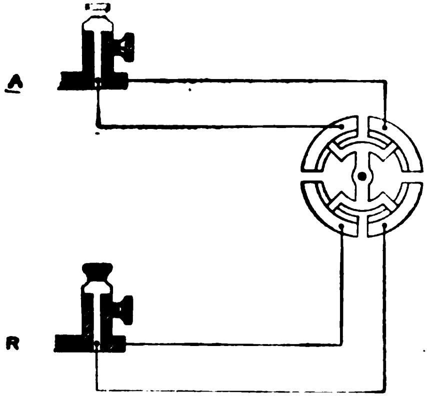

FIG. 66.—Bridge terminals.

which would tend to confusion in making the successive tests.

PRACTICAL USE OF THE BRIDGE.

The battery power required when using the bridge in conjunction with the horizontal galvanometer (Fig. 34) or the Paul unipivot galvanometer (Fig. 32) is usually of the order of 20^v. For testing insulation resistances twice this may be used when the proportionals bear the ratio of 10 and 100 respectively. For measuring very low resistances but 10 cells should be used. It may, however, be pointed out that a Wheatstone Bridge is not a satisfactory instrument for measuring resistances greatly below one ohm, owing to the resistance which is necessarily introduced in the connections which have to be made.

In measuring a resistance by means of the Wheatstone Bridge the following rules should be observed :—

1. The values of the resistance inserted in the proportionals should be as near to that of the resistance to be measured as is possible.

2. The right-hand (battery) key should be depressed before the left (galvanometer) key.

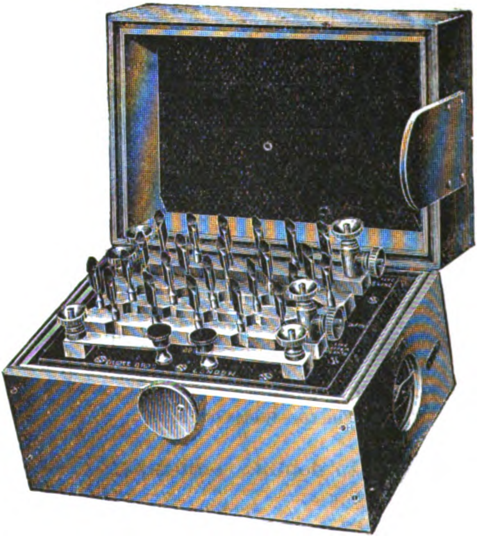

Fig. 67.—View of a Wheatstone Bridge.

3. The battery should be applied for the shortest possible time.

4. In the case of measurements of resistances containing an E.M.F. the resistance should be measured with *both* directions of current.

These rules are obtained by mathematical investigations, but they may be verified by taking a few simple numerical cases. For instance, let the rheostat arm have a resistance of 101^{ω} with 100^{ω} connected as the unknown resistance.

It will be found that with a given E.M.F. the difference of potential across the galvanometer is much greater with the two 100^{ω} proportionals than with the two 10^{ω}s or the two 1000^{ω}s. Similarly it may be shown that the galvanometer will be undeflected if the proportionals have no resistance, even when the rheostat arm has no resistance inserted whilst the fourth arm is disconnected.

Let it be known that the resistance to be measured is between 500^{ω} and 800^{ω}. From Rule 1 the values of the proportionals should be 1000 each in preference to 10 : 10 or 100 : 100. In the present case it will be assumed that the resistance to be tested is entirely free from E.M.F. Rules 2 and 3 should be observed in the case of each measurement.

Firstly, the infinity plug should be taken out and the keys depressed. If no deflection results either the battery is disconnected or the resistance to be measured is disconnected. A deflection proves that the value of the resistance is less than infinity. The direction of the deflection (usually arranged to be to the right) indicates that the resistance inserted in the box is too great.

The following operations would result—

Resistance unplugged.	Deflection towards.	Unknown resistance is.
Infinity	Right	Between 0 and infinity.
1000 ohms	Right	Between 0 and 1000 ohms.
400 ,,	Left	Between 400 and 1000 ,,
600 ,,	Left	Between 600 and 1000 ,,
650 ,,	Right	Between 650 and 600 ,
630 ,,	Left	Between 630 and 650 ,,
640 ,,	Left	Between 640 and 650 ,,
645 ,,	Right	Between 640 and 645 ,,
643 ,,	Right	Between 640 and 643 ,,
642 ,,	Nil	642 ohms.

MEASUREMENT OF RESISTANCES HAVING CAPACITY, INDUCTANCE, OR AN E.M.F.

The battery and galvanometer keys greatly facilitate the measurement of resistances having capacity or inductance. The coils of the bridge are double-wound so as to have the minimum amount of inductance. Reference to Fig. 63 will show that when the resistance unplugged in *B D* is too little the galvanometer deflects to the right, whilst too large a resistance produces a deflection to the left. If an electromagnet having a resistance of 100^{ω} is placed in the fourth arm of the bridge with 100^{ω} inserted in each of the other arms, a perfect balance will be obtained when the current has attained its steady value. By depressing the battery key before the galvanometer key, ample time will have been allowed for the current to rise to its full value in the electromagnet and the galvanometer will be unaffected. If, however, the galvanometer key is depressed before the battery key, the galvanometer will be momentarily deflected owing to the E.M.F. of self-induction opposing the current. The direction of the kick will be such as to indicate that too little resistance has been unplugged in the box.

When the resistance to be measured possesses capacity, a rush of current takes place into the cable or condenser as the case may be. This upsets the balance in the opposite direction to inductance, and the deflection therefore is such as to indicate that too much resistance has been inserted. By depressing the battery key before the galvanometer key the current attains its Ohm's law value before the galvanometer is applied, and therefore a perfect balance is obtained when the four resistances bear the correct relations to each other.

Having obtained a balance it may be asertained whether the circuit possesses capacity or inductance by depressing the galvanometer key first. Where both are present this test is inconclusive, since either may predominate or they may be balanced.

When the circuit under test has an E.M.F. in it a deflection will be observed when the galvanometer key only is depressed (provided resistances are unplugged in the proportionals). The same effect may, however, be produced by defective insulation of the testing battery, but this is readily verified by disconnecting the bridge from the line under test and leaving the earth connection. . This defect is not uncommon, especially where dry cells have to be used in the open, but it may be eliminated by standing the cells upon a perfectly dry board.

OTHER PATTERNS OF WHEATSTONE BRIDGE.

Although the P.O. form of Wheatstone Bridge is probably the pattern in most general use, it may be interesting to describe in general terms a few other arrangements. The highest type of bridge is provided with five pairs of ratio arms, 1^{ω}, 10^{ω}, 100^{ω}, 1000^{ω}, and $10{,}000^{\omega}$, and the rheostat arm having a range of $\cdot 1^{\omega}$ to $10{,}000^{\omega}$ by gradations of $\cdot 1^{\omega}$ is arranged on the single-plug principle, either as shown in Fig. 23, or with the resistances ranged round a dial plate. Again, bridges are made in which plugs are dispensed with in favour of radial-arm contacts arranged after the fashion of the D rheostat—an example of this construction is seen in the resistance box of the bridge-megger. Wheatstone Bridges are made in endless variety from the high-grade instrument with a huge range of measurement down to the rough, workshop type with limited range and coils adjusted only to approximate accuracy.

PART II.—THE MEGGER AND BRIDGE MEGGER.

The Megger, which is the result of evolution from the original Evershed Ohmmeter,* consists of a direct current generator, and moving double coil instrument contained within a single case. The resistance of a circuit in which a current is flowing is equal to the E.M.F. divided by the current. If one of the two coils be urged with a force directly proportional to the current flowing and the other coil, attached to it, acting as controlling coil, is urged in the opposite direction with a force proportional to the E.M.F. and to the distance through which the coil is turned, the position which the pair of coils takes up will depend on the ratio existing between *E.* and *C.*, *i.e.* upon the resistance of the circuit. The pointer attached to the coils moves over a scale marked in ohms.

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* Perren Maycock's *Electric Lighting and Power Distribution*, Vol. I. p. 346.

The general arrangement of the Megger is indicated in Fig. 68. The two bar magnets *SN* and *NS* magnetized to about 2000 Gausses, furnish the magnetic field for the dynamo or generator *G* and the moving-coil system *PC*. The current coil moves in the uniform field in the spaces between the fixed soft iron core and the pole pieces, and a current passing through it tends to turn it in the direction shown by the arrowheads—the arrangement so far being identical with that of an ordinary D'Arsonval galvanometer (compare Fig. 45). It will be observed that the core *I C* is split, and that in the position shown the pressure coil, which is threaded by the core, lies over this air gap. The magnetic field threading the pressure coil is weakest at this point, and as the coil deflects to embrace *I C* the field becomes stronger. A current in the pressure coil alone tends to hold it in the position shown. When both coils carry a current, the two coils and the pointer move until the forward pull of the current coil is balanced by the increasing backward drag of the pressure coil. Extremely fine phosphor bronze wire is used to lead the current to the coils, and is so arranged as to produce no appreciable opposition to the movement of the coils.

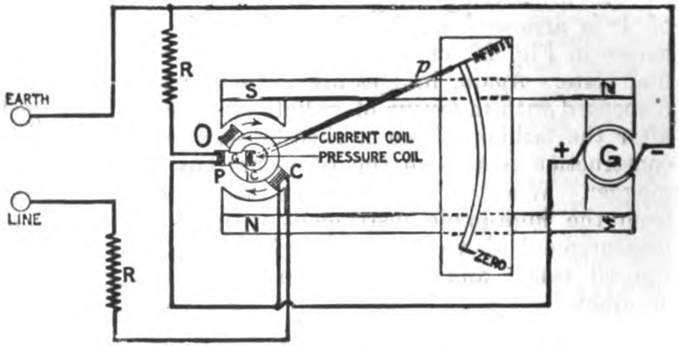

Fig. 68.—Principle of the Megger.

With the handle of the generator at rest, the pointer is entirely free and will rest anywhere on the scale.

The generator is driven through gearing by revolving the handle to be seen in Fig. 69. A centrifugal governor and friction clutch ensure that the speed of revolution of the armature, and therefore the voltage generated, is maintained constant when the handle is turned at slightly above 120 revolutions per minute. The remarkable constancy of the E.M.F. generated is of especial importance in testing cables or similar circuits possessing capacity—since a variable E.M.F. necessarily involves condenser currents through the instrument producing variable readings.

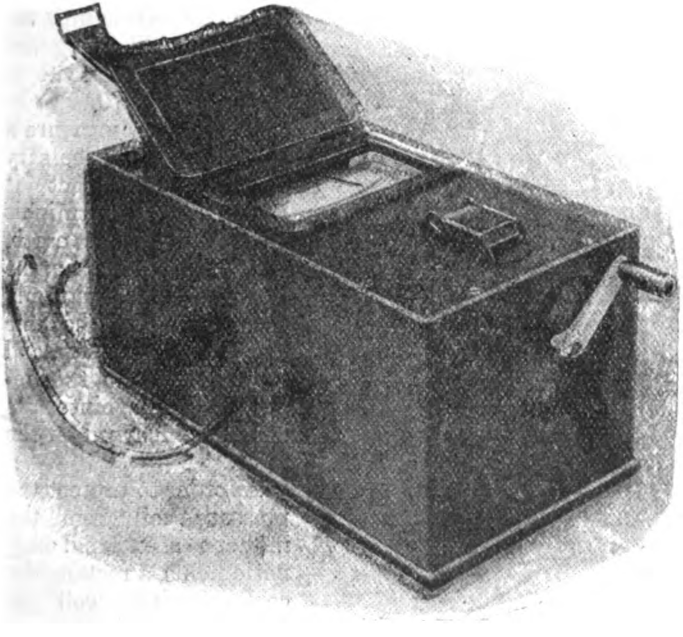

FIG. 69.—View of megger.

The pressure coil is connected with a series resistance directly across the generator terminals, whilst the current coil is connected in series with the resistance to be measured, a suitable resistance inside the case being placed in series with it, to prevent mechanical damage to the instrument in case of short circuit. This resistance is, of course, taken into account in calibrating the scale—a typical scale is shown in Fig. 70.

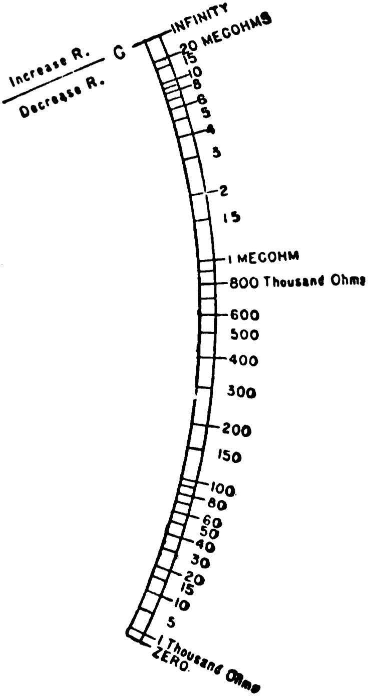

Fig. 70.—Scale of megger.

In order to measure a resistance, it is necessary merely to connect it between the terminals marked line and earth, and to turn the handle steadily and uniformly at such a speed that the clutch is felt to slip, and to read opposite the deflection of the pointer the resistance marked on the scale.

In order to protect the pressure coil from the influence of external magnetic fields, a rectangular compensating coil in series with it is fixed on the end of the pressure coil, and so joined up that any E.M.F. induced in the pressure coil is balanced by the equal but opposite E.M.F. induced in the compensation coil. This precaution is necessary because the pressure coil is not, like the current coil, always wholly within a field of large and uniform intensity. The pressure and compensation coils are fixed in the same plane, but the latter is not shown in Fig. 68, which illustrates merely the general principle of the instrument.

The instruments are constructed with various ranges of measurement and with generators giving from 100^v, 250^v, 500^v and 1000^v. The high range megger used by the Post Office reads from 5 to 1000 megohms with a pressure of 500^v, which latter constitutes the highest voltage used by the Dept. The low range megger reads from 1000^ω to 10 megohms with a pressure of 100^v, and a switch can be added to give a range 100^ω to 1 megohm.

Another feature of the instruments consists in the use of the Price guard wire device which secures that neither internal nor surface leakage can affect its readings. Any error due to leakage across the surface of the insulator under test is eliminated by wrapping a wire round the insulation between the conductor and earth, and attaching it to the guard wire terminal of the instrument (Fig. 71). The guard terminal is connected to the positive terminal of the generator, and there is therefore no difference of potential between the conductor and the point at which the guard wire is attached, and, on the other hand, any current escaping over the outside of the conductor to water does not pass through the current coil of the megger. It may be remarked that in testing the insulation resistance of cables the matter is one of great importance, since it often happens that the insulation resistance of the cable proper is much higher than the insulation resistance of its ends.

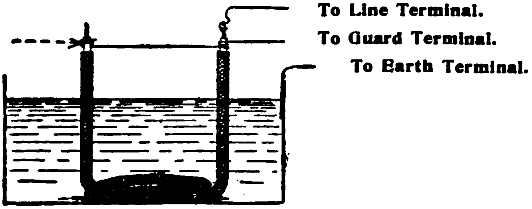

FIG 71.—Price guard-wire device.

The condition of the instrument may readily be verified by measuring the insulation of a $7\frac{1}{4}$ m.f. condenser. To remove all traces of previous absorption charge, the condenser should be short-circuited for a few minutes prior to the test. The insulation should, after the first throw to zero, during the charging of the condenser, rise evenly and steadily during the one minute's electrification (see page 743). An unsteady reading is an indication of varying voltage, a defect which should not occur if the handle is turned at a uniform speed slightly in excess of that at which the clutch slips. After the test the condenser should again be short-circuited, and, owing to the high voltage of the megger, it is advisable to use an insulated wire for the purpose.

THE BRIDGE-MEGGER.

This instrument with the change-over switch at "Megger," has a range of 1000^{ω} to 20 megohms at 250^{v}, as indicated by the scale reproduced in Fig. 70. With addition of a resistance box connected to the megger, and by turning the switch to "Bridge" the instrument is converted into a Wheatstone Bridge. The switch places the two windings of the generator armature in parallel, thus reducing the voltage to 125^{v}, but increasing the maximum current which generator can deliver. The pressure coil is used as the control coil and holds the needle at infinity when the current coil, used as the galvanometer, carries no current. The ratio arms consist of a resistance with three taps so arranged that the resistance measured is equal to one-tenth of, or one-hundredth of, the resistance inserted in the box, according to the position of the switch. The direct reading resistance box consists of four radial arm rheostats, each with 10 coils, units, tens, hundreds, and thousands. To each radial arm is attached a figure dial arranged to show (through a window in the top plate) a digit representing the position of the switch. The total resistance is thus given directly as a row of figures. Thus in Fig. 72 the resistance x is 2714^{ω}. Had the ratio switch been placed at "100" the resistance would have been $27{\cdot}14^{\omega}$.

The connections are shown in full in Fig. 72, and in comparing them with the theoretical diagram (Fig. 73) it will be observed that a resistance *r* is placed in series with the generator and bridge in order to prevent the

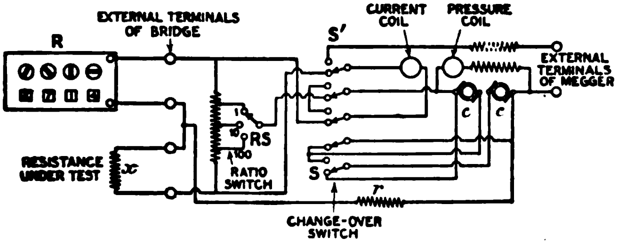

Fig. 72.—Full connections of bridge-megger.

current exceeding reasonably safe limits when measuring low resistances.

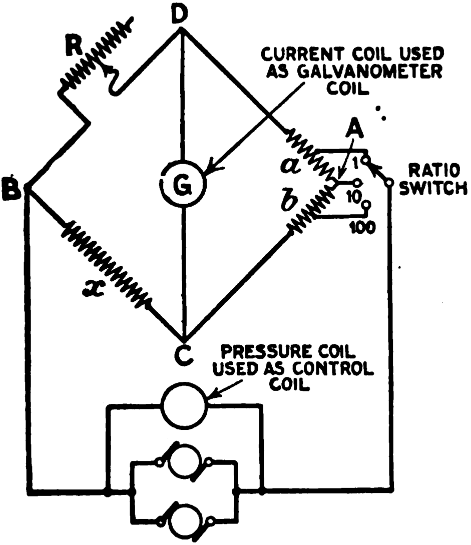
D
R
CURRENT COIL USED AS GALVANOMETER COIL
A
a
1
RATIO SWITCH
B
G
b
10
100
x
C
PRESSURE COIL USED AS CONTROL COIL

Fig. 73.—Theoretical connections of bridge-megger.

The general appearance of the apparatus is conveyed by Fig. 74.

The bridge-megger may be used to measure accurately any resistance from 1^{ω} to 9999^{ω} by the bridge method, and thence by the megger proper to 20 megohms. The advantage gained by dispensing with batteries can scarcely be over-estimated.

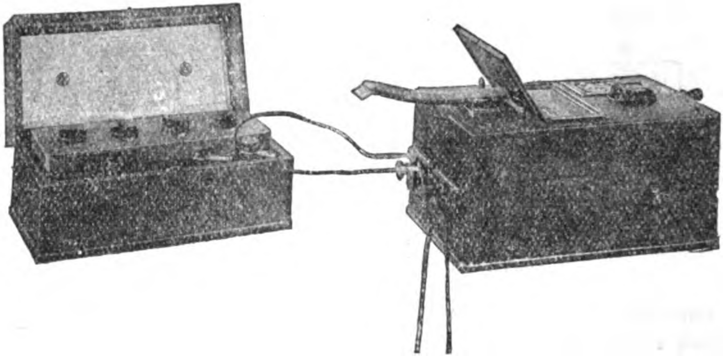

FIG. 74.—View of bridge-megger and resistance box.

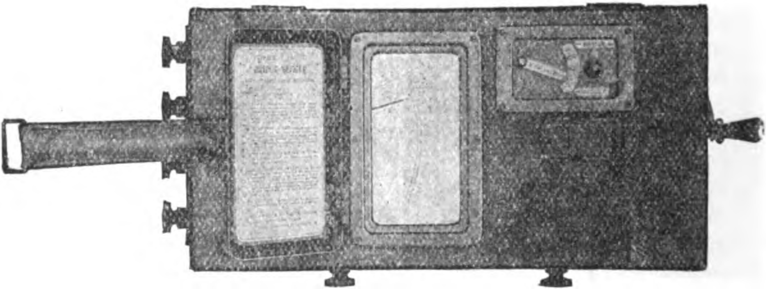

FIG. 75.—Plan view of bridge-megger.

PART III.—VARIOUS METHODS.

The choice of the method of measuring a resistance depends upon the value of the resistance, the degree of accuracy required, and upon the apparatus available. For resistances ranging from an ohm or two up to a megohm the Wheatstone Bridge is usually employed. Above this value either a megger or a deflection test is used.

VERY LOW RESISTANCES.*

For resistances of the order of a fraction of an ohm a fall of potential test is usually employed, but as it is seldom necessary in practical telegraphy to determine resistances of this order it will suffice to say that if the resistance to be measured is placed in series with a standard low resistance (say $\cdot 01^{\omega}$) and a steady current flows through them the difference of potential between the ends of each is proportional to their resistances. The differences may be compared with the aid of a galvanometer of high resistance alternately connected across them or by the potentiometer. Again, by passing a known current (observed on an ammeter placed in series) and reading the difference of potential across the resistance with a low reading voltmeter, the resistance is obtained by dividing the voltage observed by the current.

ROUGH METHODS.

A rough method of measuring ordinary resistances met with in telegraphy consists in connecting up a battery, galvanometer, and the resistance to be measured, and observing the resulting deflection which should be as near the angle of maximum sensitiveness as possible. A rheostat is then substituted for the resistance and the deflection reproduced by introducing resistance into the rheostat. When this has been done the rheostat resistance is equal to the unknown resistance.

With the aid of a differential galvanometer, battery, and rheostat the unknown resistance may be balanced by the rheostat as is done on a duplex circuit. This method and the substitution method previously described should be regarded only as very rough approximations.

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* Perren Maycock's *Electric Lighting and Power Distribution*, Vol. I. p. 327 *et seq*.

VOLTMETER METHOD.

An approximate method which is much used in telephone test rooms consists in the provision of a battery having an E.M.F. of 40^v with a tap at 4^v, and a voltmeter having a resistance of $10{,}000^\omega$ reading from 0 to 4^v, and, with the aid of a multiplier, bringing the resistance up to $100{,}000^\omega$, also reading 0 to 40^v. It is first ascertained that the voltage of the battery (usually of dry cells) is 40^v, and the voltmeter is then placed in series with the battery and the resistance to be measured. If the voltmeter with $100{,}000^\omega$ shows 20^v the unknown resistance is equal to the voltmeter resistance, the battery resistance being negligible. If 10^v it is $300{,}000^\omega$. With a 4^v battery and $10{,}000^\omega$ voltmeter, resistance 2^v corresponds to $10{,}000^\omega$, and 1^v to $30{,}000^\omega$. With the aid of a $\frac{1}{10}$ shunt (1111^ω) on the voltmeter 2^v corresponds to 1000^ω, and 1^v to 3000^ω. Measurements may be made on this principle with a No. 2 Detector and the 40^v secondary cell lead, the unknown resistance is then $\left(\frac{40}{V}-1\right)\times 5000^\omega$, or with a 4^v battery $\left(\frac{4}{V}-1\right)\times 500^\omega$ where V is the reading of the detector in volts.

DIRECT DEFLECTION METHOD.

For the measurement of extremely high resistances a high resistance reflecting galvanometer provided with shunts, a megohm standard resistance, and a battery are required. With the battery, megohm resistance, and the galvanometer shunted $\frac{1}{1000}$ in series, and to facilitate the calculation of the results, a deflection of 100 divisions is obtained by adjusting the controlling magnet. Neglecting the resistance of the battery and galvanometer, it may be assumed that the same deflection would have been obtained through 1000 megohms with the galvanometer unshunted, and that a deflection of 1 division would be obtained through a resistance of 100,000 megohms. Now if the battery and galvanometer be connected to the resistance to be measured, its resistance will be $\frac{100{,}000}{\text{Deflection}}$ megohms. If shunts have to be employed the result is divided by the power of the shunt used.*

INSULATION TESTING SET.

The "insulation testing set" illustrated in Fig. 76 consists of a horizontal galvanometer of the same general form as that illustrated in Fig. 34, but wound to a resistance of 25,000$^{\omega}$. The scale is divided into equal divisions, and the skew scale principle adopted in order to increase the range. The battery power consists of six 50-cell dry batteries contained within six boxes. These cells are of a very small size, but are quite adequate for this purpose, since the currents needed are usually very small fractions of one milli-ampere. The E.M.F. of the battery is roughly 450 volts.

Each box is provided with four terminals, so that 1, 10, or the whole of 50 cells, may be connected up, and a 1000$^{\omega}$ resistance coil is also included so that the possibility of a short circuit may be avoided. The boxes should stand upon a thick sheet of gutta-percha, so as to ensure satisfactory insulation. The battery leads are connected to the battery terminals by means of clips having insulated handles, thus avoiding the possibility of electric shocks which might result from handling the terminals.

The switch is first turned to the "constant" position, and the deflection observed. It will be seen that the battery is connected in series through a resistance of 100,000$^{\omega}$, and

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* The accurate formula is :—

$$x = \frac{d^1}{d^2}\left\{\frac{G+S}{S}(R+B) + G\right\} - (G+B)$$

where d_1 is the constant,
d_2 is the observed deflection,
G, S, R and B are respectively the resistances of the galvanometer shunt, resistance coil and battery.

In taking the insulation resistance of cables all quantities save the multiplying power and the resistance coil may be neglected.

that the galvanometer is shunted $\frac{1}{1000}$. With these conditions the constant obtained is usually about 15°. With the galvanometer unshunted the same battery would produce a deflection of 15° through $100{,}000^{\omega} \times 1000 = 100$ megohms. The degrees may be assumed to be roughly proportional to the current, and therefore the resistance corresponding to any deflection is, assuming the constant to be 15° :—

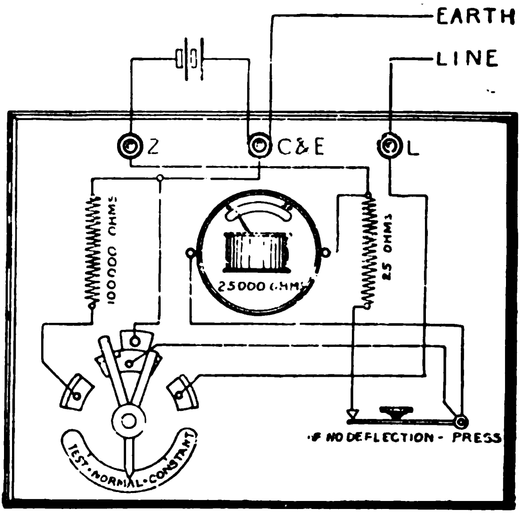

Fig. 76.—Insulation testing set.

$$\frac{1500}{\text{Deflection}} \text{ megohms unshunted}$$

and

$$\frac{1{\cdot}5}{\text{Deflection}} \text{ megohms when shunted } \frac{1}{1000}.$$

The switch is turned to "test," and one minute later the key is pressed, thus removing the shunt from the galvanometer, and the deflection observed. When the deflection is beyond the scale with the key depressed and is imperceptible with the $\frac{1}{1000}$ shunt in, the battery power is reduced sufficiently to obtain a reading, and the constant with the reduced power noted or calculated as being reduced in the ratio of the total number of cells to the number used for the test. In order to discharge the cable an earth-connected stud, which is passed over by the longer end of the contact spring in its passage from "test" to "normal" position, has been added.

When testing the insulation of unscreened wires contained in a lead-covered cable difficulty frequently arises owing to the inductive action of the working circuits in that cable. Since such wires are invariably arranged in twisted pairs a differentially wound galvanometer (12,500$^{\omega}$ per coil) is employed, one coil being connected to the battery and wire under test, whilst the other coil is connected to the companion wire and earth through a resistance equal to that of the testing battery which (with the 1000$^{\omega}$ coils in the boxes) will be 1100$^{\omega}$ per 50 cells. In this way the currents induced upon the wire under test are exactly balanced by those induced upon the companion wire of the pair, since the two coils are joined up so as to oppose. Both wires are, of course, disconnected for the test.

CHAPTER VI

SINGLE CURRENT SYSTEMS AND RELAYS.

EARTH RETURN.

TWO conducting paths are required between the battery and the apparatus to be actuated by the current, in order that the circuit may be complete. For one of these paths the earth itself is employed, thus saving the extra cost, extra battery power and the extra liability to faults which the second wire entails. The earth return may be regarded as a perfect path having no resistance.

There are two theories in regard to the behaviour of the earth as a return current conductor. The first considers the earth a vast reservoir of electricity and therefore obviates the necessity of imagining that each current returns directly to its own battery. An analogy of a long pipe, with both ends dipping into the sea, and containing a rotary pump will serve to illustrate this theory. Imagine that the pipe is, say, ten miles long and that it is full of water. The pump is worked and water is picked up from the sea at one end and discharged back again at the other. Let the rate be, say, a gallon a minute. Every minute one gallon of water is picked up at one end of the pipe and a precisely equal quantity discharged at the other. Water momentarily accumulates in the sea at one end and its quantity is reduced at the other. The adjustment is one of general level between the two places, and it is therefore not a case of an identical gallon-a-minute stream going back through the sea in the same form that it passed through the pipe. So with an electric circuit; at one end electricity is continuously passed into the earth, and at the other continuously passes out in exactly equal quantity, the adjustment being one of level merely between the two ends of the circuit.

The second theory and probably the more correct one is that the current actually traverses the earth, which, on account of the vast volume of material between the two plates, forms a path of practically no resistance. There are one or two difficulties which may at the outset be detailed and explained. Let there be three circuits working between Manchester and Liverpool and let two of these send 15 m.a. *to* earth, whilst one is receiving 15 m.a. *from* earth. Two currents in opposite directions cannot exist in one conductor at the same time. The explanation is that the batteries combine at the sending end, and it is only the balance of current which is conveyed by the earth.

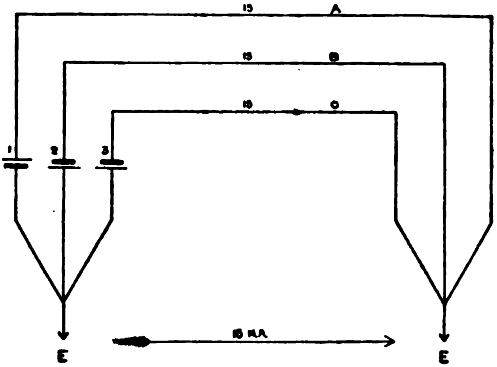

FIG. 77.—Principle of earth return.

The conditions are shown clearly in Fig. 77. The current actually flowing through the earth is in this case 15 m.a. Batteries 1 and 2 may be imagined as connected in series to a circuit consisting of *A* as direct circuit, and *B* as return circuit also connected in series, and the earths entirely ignored. This argument gives precisely the same value of current in each circuit, but with opposite directions. The remaining battery sends its whole 15 m.a.

via *C* and earth. This simple explanation, although illustrating the general principle, is not quite correct; the obvious objection being that there is no reason why battery 2 should combine with 1 rather than 3. The fact is that it combines with both. Batteries 2 and 3 each send 7½ m.a. to earth, whilst the 15 m.a. going to the negative of 1 is made up of the remaining 7½ m.a. from battery 2, and 7½ m.a. from battery 3. A careful consideration of any required combination will show that the batteries combine in series as far as possible, and that the earth then conveys the balance of current.

At all large offices a very considerable number of circuits are always simultaneously sending and receiving currents of varying directions and magnitudes, and as these currents are all dealt with by the same earth connection, the truth of explanations given above will be realized.*

EARTH CONNECTION.

The earth connection is made by sinking a galvanized iron plate 2 feet 6 inches square into the ground. Soldered to the plate is a stranded copper wire and to this the earth connection from the instruments is led. At a large office several plates are sunk and all are connected together in order to form a connection to earth of the least possible resistance. The plates should be sunk in damp ground, and where this cannot be obtained recourse must be had to neighbouring watercourses. At local offices the earth connection is often made by screwing a clip on the water pipes. If gas pipes are employed the connection should be made upon the road side of the meter. No earth which has a resistance exceeding 10^{ω} can be considered as efficient. For very large offices this figure is altogether too high, and, as previously mentioned, several separate earths are used.

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* It is quite open to question whether any real difference exists between the two theories given. Using the analogy of the pipe and rotary pump, it may be pointed out that, if the flow of water is very considerable, a strong current would set in between the ends of the pipe.

ELECTROMAGNET.

Since iron conducts lines of force far better than air, the introduction of iron into the magnetic circuit or path of the lines of force greatly increases their number. In order to obtain a magnetic field of considerable strength from a comparatively small current, it is necessary to have a large number of turns of wire and to introduce into the magnetic circuit as small an air-gap as possible.

An electromagnet and armature are conventionally depicted in Fig. 78, the path of the lines of force being indicated by the dotted line. In order that the circuit may be as shown, the polarities of the upper ends of the cores must be opposite in character—a result which is readily obtained by reversing the direction of winding in the case of the second core. Under the conditions illustrated in the figure, the top of the left core is North and the top of the right core South.

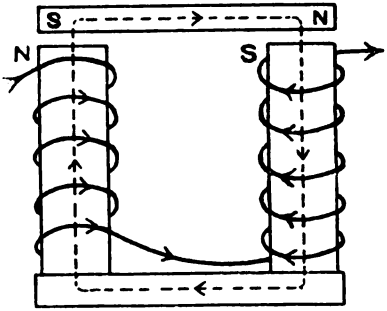

FIG. 78.—Magnetic circuit of a sounder.

NORTH POLE OF SOLENOID.

The hand rule given upon page 10 shows how the direction in which the N. pole of a needle moves may be predicted when a current-conveying wire is placed above or below it. This rule applies in a similar fashion for finding the N. end of a solenoid. The right hand is placed round the solenoid so that the current is flowing in the direction of wrist and fingers, and the outstretched thumb will then indicate the North end of the solenoid.

The result of energizing the electromagnet is that the armature is attracted. This may be regarded as the result of the tension along the lines of force which causes them to shorten by producing a downward movement of the armature. It may also be regarded from the point of view that the armature assumes an induced polarity as shown by the figure, and that attraction results.

RESIDUAL MAGNETISM AND RETENTIVITY.

Soft iron, more than any other material, is subject to residual magnetism; in the case of a very long rod or wire, it has been found that upon disconnecting the magnetizing current 93% of the magnetism remained. The smallest mechanical vibration or the use of an extremely small opposing magnetizing force, however, at once reduces the value of the residual magnetism to zero.

The explanation of the phenomenon may be deduced from the molecular theory (Appendix A.).

If a coil of wire is wound upon a continuous ring of iron and a current is passed through the windings the iron becomes magnetized. Upon cessation of the current the magnetism will still remain, because there is nothing which tends to demagnetize it. The molecules form a continuous chain around the ring. The lines of force are therefore circles inside the ring itself, and there are no external North and South poles. In order to demagnetize the ring it is necessary to disturb the closed chains of molecules, and this may be done by either a reverse current which reverses the direction of the magnetic field through the iron, or by shaking or hammering the iron and so disturbing the molecular chains. If now the ring is cut and straightened out it will be found that the iron becomes demagnetized immediately the current ceases, and that the amount of residual magnetism is enormously reduced. The reason is that the lines of force in this case have to pass from the North to the South pole of the iron through the badly conducting air. Demagnetization may legitimately be regarded as due to the attraction between the North and South poles of the magnet acting through the length of the magnetized iron. In the case of steel it has been remarked that this effect, even in very short lengths of steel, is not sufficiently great to produce demagnetization, and the result is a permanent magnet. In order that demagnetization may be rapid and complete an iron core should be as short as possible.

Applying this knowledge to the case of an electromagnet it will be seen that the nearer the conditions of the closed ring are reproduced the greater is the value of the magnetization which remains upon cessation of the current. When the armature is allowed to touch the cores no definite poles are created and there is little or no demagnetizing tendency, consequently the armature "sticks."

It is therefore essential that a small air-gap shall be left in order that demagnetization may be produced by the action of the poles. It may also be remarked that the shorter the electromagnet and the longer the air-gap the more rapid and complete is the demagnetization. With steel the values of the residual magnetism are not so large as with soft iron, but the demagnetizing tendency of the poles is quite insufficient to produce demagnetization. This fact is expressed by saying that the retentivity of steel far exceeds that of iron.

SOUNDER.

The Post Office pattern of sounder, shown in Fig. 79, consists of an electromagnet with a soft iron armature held away from its cores by an antagonistic spring. The tension upon this spring is adjusted by means of the screw supported on the brass base of the instrument. The armature is fixed to the square and somewhat heavy brass bar which is carried upon a steel axle with pointed ends. The ends of the axle are held in the hollowed ends of two screws, one of which is clearly visible in the figure. The armature bar carries a transverse screw which determines the proximity of the armature, when depressed, to the cores. The clearance should always be at least equivalent to the thickness of a sheet of good notepaper in order to avoid trouble due to residual magnetism. The screw immediately in front determines the amount of play to be given to the armature. It should be noticed that the armature adjustment and the axle screws are all four of them provided with a screwed washer, or clamping screw, which banks against the fixed portions. This serves to preserve the adjustments by preventing the screws from working loose.

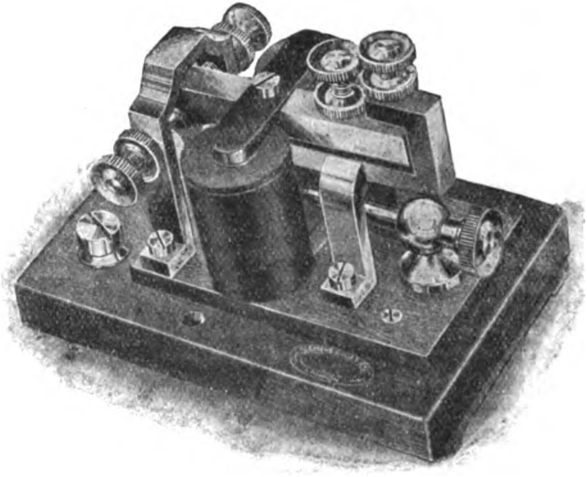

Fig. 79.—P.O. sounder.

Earlier forms of sounder were wound to a resistance of 40^{ω}, and a 500^{ω} shunt was connected across its terminals, so reducing the joint resistance to 37^{ω}. This gave way to one wound to 20^{ω} with a 500^{ω} shunt, *i.e.* $19{\cdot}2^{\omega}$ joint resistance. This has now been abandoned in favour of a 21^{ω} coil and 420^{ω} shunt which together give a joint resistance of 20^{ω}. Sounders for secondary cell working (Chapter XVIII) have a resistance of 900^{ω} (1000^{ω} coil with a 9000^{ω} shunt), and are worked with 24^{v}.

The figure of merit of the 37^{ω} sounder is 55 m.a., that of the $19{\cdot}2^{\omega}$ sounder is 69 m.a., and that of the 20^{ω} sounder is 55 m.a.

POLARIZED SOUNDER (ORIGINAL PATTERN).

With the ordinary sounder a current in either direction will actuate the instrument, and it is therefore termed a non-polarized instrument in contradistinction to polarized instruments in which the motion of the armature depends on the direction of the current. Generally, polarized instruments are also more sensitive than non-polarized instruments of the same type.

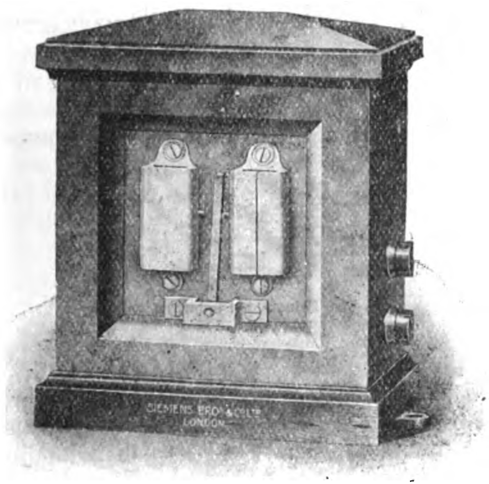

FIG. 80.—Front view of polarized sounder.

The original polarized sounder consists of an electromagnet with an armature centrally pivoted above it, the armature and cores being inductively magnetized by a permanent magnet as indicated in Fig. 81. The ends of both cores are N. poles and the ends of the armature are both of S. polarity. The passage of a current in the direction indicated by the arrows increases the strength of the left N. pole, and reduces or reverses the polarity of the right core, thus causing the armature to tilt from the dotted position to the position shown by the full lines. Reversal of the current restores the armature to the dotted position. It should further be noted that the armature remains in whichever of the two positions it is placed.

The 4500$^{\omega}$ polarized sounder (coils 5400$^{\omega}$ and 27,000$^{\omega}$ shunt) is illustrated in Figs. 80, 81, and 82. The spindle upon which the armature is pivoted passes through the dial and carries a vertical striker of hard brass playing between two metal pins attached to the sounding pieces. The metal of the left or spacing sounding piece is 30 mils in thickness, as against the 20 mils of the right one which is split vertically.

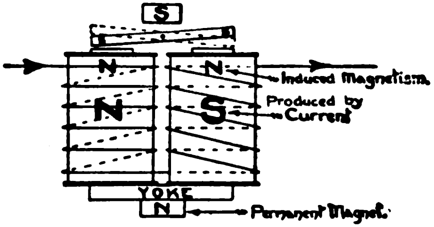

FIG. 81.—Principle of polarized sounder.

In its first form the instrument was differentially wound, the idea being to produce an instrument which could be used for several purposes. It could be used in place of (i) a single needle dial; (ii) the relay, plate sounders and local battery of a double plate sounder; (iii) the relay, sounder and local battery of any single or double current sounder either simplex or duplex. In order to admit of its use in cases (i) and (ii) two spiral springs are provided attached to a downward projection of the armature spindle, by the aid of which the striker may normally be maintained in a central position between the two sounding pieces. For single current sounder working, the right-hand spring (Fig. 82) only would be employed. In the cases in which the 4500ω sounder is used the springs are usually removed, but the provision has been made for a few special cases in which the instrument is required to respond to single current impulses.

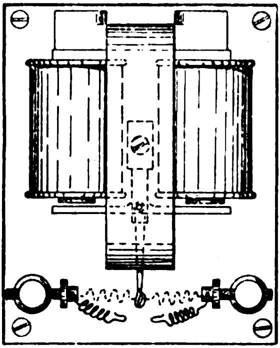
FIG. 82.—Back view.

The instrument has two disadvantages, firstly, its signals are not loud enough for use in a large office, and secondly, complaint is made of the irritating character of the sound and the liability to sound reversed.

VYLE POLARIZED SOUNDER.

The principle of this instrument, invented by C. C. Vyle,* is illustrated in Fig. 83. The yoke of an ordinary sounder is replaced by a permanent magnet, separated from the cores which it polarizes by a layer of non-magnetic material providing the equivalent of an air-space of 5 mils. It is, in fact, a Hughes electromagnet with its parts somewhat differently disposed, the permanent magnet being fixed in the base of the sounder at right angles to the cores.

When the instrument is properly adjusted the upper and lower positions of the armature are positions of balance which the smallest impulse upsets, thus starting the armature movement. In the upper position the force of the antagonistic spring prevails, whilst in the lower position the magnetic attraction exceeds the upward pull of the spring. The pull of the cores on the armature varies inversely as the fourth power of the distance separating them, whilst the pull of the spring varies directly only as the distance through which the armature descends, and therefore the armature, whether moving upwards or downwards, is continually and rapidly accelerating and consequently makes a considerable impact when arrested by either of the limiting stops. Further, it may be added that the instrument works on that part of the magnetization curve (described as the second stage of the magnetization, Appendix A), where relatively small changes in magnetizing force produce large flux variations, thus materially increasing its sensitiveness.

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* "The Polarized Sounder," by C. C. Vyle and E. V. Smart, *Post Office Electrical Engineer's Journal*, Vol. I. p. 6.

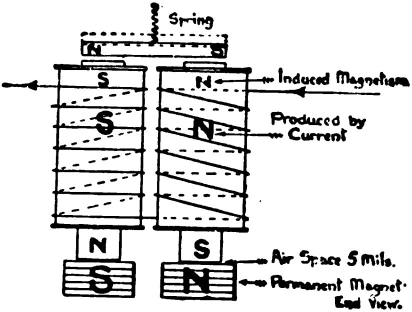


FIG. 83.—Principle of Vyle polarized sounder.

The air-gap between the magnet and the cores is of vital importance, since it ensures that the passage of working currents shall not affect the strength of the permanent magnet.

The polarized sounder (Fig. 84) is wound differentially, and with coils each of 500^{ω} resistance can be actuated with a current of ½ m.a.; 3 m.a. suffice for signals at the rate of 20 words per minute, whilst with 10 m.a. loud strong working signals are produced. The distance between the cores and the armature when down should be 8 mils, and the play of the armature between the limiting stops should be 16 mils. Gauges to secure these distances have been made, and the range of the instrument is without any change in adjustment of the tension from 3 m.a. to 40 m.a. By increasing the tension much larger currents may, if necessary, be used.

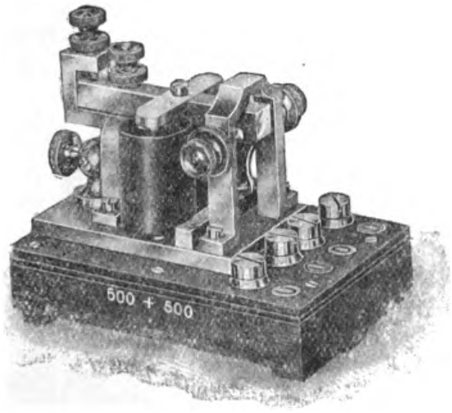


Fig. 84.—Polarized sounder $500^{\omega} + 500^{\omega}$.

The inductance of this instrument is 62 henrys, and this serves to simplify the capacity balance on long or wholly underground circuits.

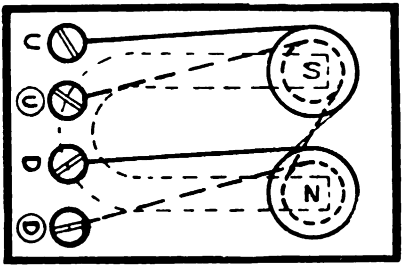


Fig. 85.—Windings of polarized sounder $500^{\omega} + 500^{\omega}$

These sounders are wound to various resistances, *e.g.* $100^{\omega}+100^{\omega}$, 2000^{ω}, 4500^{ω}, etc.

Consideration will show how readily ordinary sounders may be converted to the Vyle principle.

A recent improvement in the design consists in replacing the screws which determine the play of the armature and its proximity to the cores by fixed stops, thus leaving the tension of the spring as the only adjustment. The armature axle screws have been similarly fixed (Fig. 86).

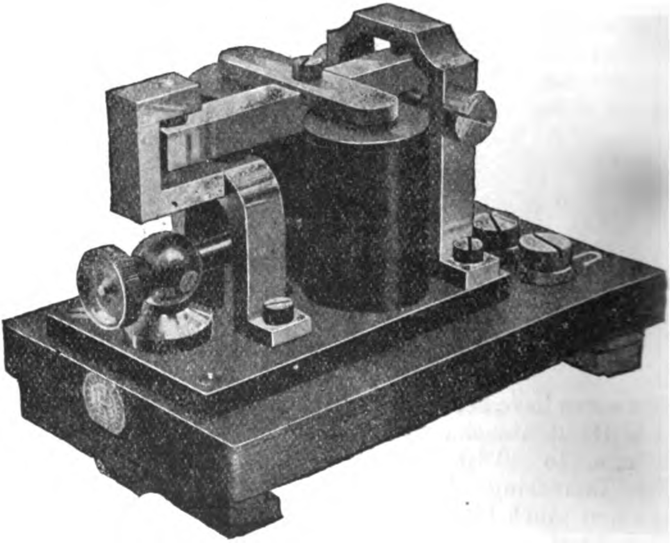


Fig. 86.—Polarized sounder with fixed adjustments.

THEORY OF POLARIZED SOUNDER.

Let d = distance between cores and armature.
m = magnetic force due to permanent magnet.

The induced magnetic strength of the armature will be $\frac{m}{d^2}$

$\therefore$ the attraction f_1 between the core and the armature will be

$$f_1 = \frac{\frac{m}{d^2} \times m}{d^2} = \frac{m^2}{d^4}$$

Suppose that in the lower position of the armature d is halved

$$f_2 = \frac{m^2}{\left(\frac{d}{2}\right)^4} \text{ and } f_2 \Big/ f_1 = \frac{m^2}{\left(\frac{d}{2}\right)^4} \Big/ \frac{m^2}{d^4} = 16:1.$$

Now consider the spring; its original tension f_1 and for a displacement $= \frac{d}{2} = f_1 + \left(c \times \frac{d}{2}\right)$ where c is a constant.

But the spring would have to be stretched considerably to double its original tension, and as it is obvious that it is only stretched a fraction of its length, its tension is something much less than twice f_1, so that:—

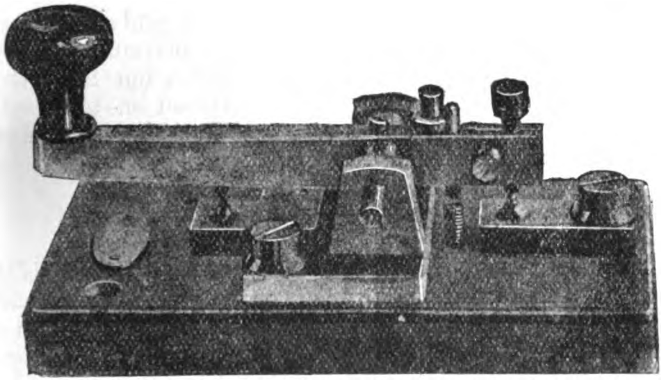


FIG. 87.—Single current key.

$$\frac{\text{Rate of increase of magnetic attraction}}{\text{Rate of increase of spring tension}} \text{ is at least } 8:1.$$

During the upward movement the spring tension and magnetic attraction both decrease, but the latter falls off very rapidly (as the fourth power of the distance), whilst the spring tension decreases as the distance simply.

SINGLE CURRENT KEY.

The single current key (Fig. 87) consists of a pivoted brass lever playing between two contacts, but normally held against the back contact by a spring. The underside of the lever in front is furnished with a platinum contact which, when the key is depressed, comes into contact with a similar stud fixed to the brass plate and terminal. The back stop, so termed in contradistinction to the front stop, is also tipped with platinum and normally makes contact with the adjustable contact screw which passes through the lever. It should be noted that the lever is split from the end for a short distance, and that a screw is provided for tightening the grip upon the contact screw, thereby tending to preserve its adjustment. The tension adjustment is quite obvious.

Recently it has been decided to use a gold-silver alloy (10% gold and 90% silver) instead of platinum on the contacts of telephone apparatus generally, but the more expensive platinum contacts are still used on telegraph apparatus generally, with the exception of single, double current, and electro-magnetic indicator keys.

SINGLE CURRENT GALVANOMETER.

The galvanometer employed is of what is officially designated the "single current" type. Its coils are wound upon two bobbins, and in all the later forms its magnetic needle is of soft iron rendered magnetic by induction from permanent magnets. This arrangement avoids demagnetization of the needle by the passage of the working currents or by the portion of a lightning discharge which sometimes passes through the coils of the instrument. The arrangement is practically identical with the Varley type of single needle dial described later. Its general appearance is indicated in Fig. 88, from which it will be noted that the dial is not divided into degrees, but, instead, two ivory stop-pins are provided for limiting the range of the deflection. The two terminals of the instrument project horizontally from the back. The top of the needle deflects in the direction in which the current passes through the instrument. For example, if the current passes from the right to the left-hand terminal the top of the needle moves over to the left. This rule applies to every form of galvanometer or needle dial employed by the Department.

The instrument has a resistance of 30^{ω} and a figure of merit of 9·3 m.a., with which current the needle should be deflected to either stop-pin. It is employed upon simplex circuits, both single and double current, but not upon Wheatstone circuits.

A single current galvanometer with an engraved dial has, however, been introduced for use on central battery telegraph circuits.

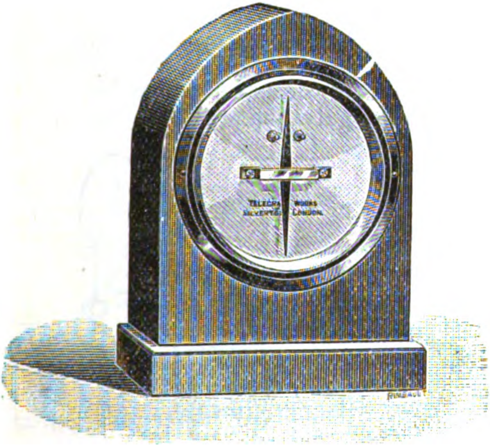


Fig. 88.—Single current galvanometer (resistance 30^{ω}).

Up and Down Stations.

Uniformity in connections is a most important matter on account of the difficulty of locating faults upon circuits which are not joined up according to a definite system. It is also desirable that all circuits fitted with the same type of apparatus should be joined up alike at the instrument tables. The connection of the set as a whole to line and earth differs at the ends of a circuit in order that the connections at the tables may not vary, and it becomes necessary to distinguish between the two ends of the circuit.

One end is termed the up station and the other is called the down station. The station nearest to London is "up" and that furthest removed from London is "down." For example, London is the up station upon any London circuit. In the case of a Manchester-Newcastle circuit, Manchester is up and Newcastle down. It will be found that the up station always connects the positive pole of the battery to the line when sending a marking current, hence the common phrase or statement that "the up station sends copper to line to mark."

DIRECT SOUNDER CONNECTIONS.

A direct sounder set consists of a sounder, single current key, single current galvanometer, 5^{ω} resistance coil, and battery. It is so termed because the received current makes the mark directly and not indirectly, *i. e.* by the aid of a relay. The right side of the galvanometer is the "down instrument terminal," and the junction of the sounder and negative pole of the battery is the "up instrument terminal." The apparatus connections are shown in Fig. 89, whence it will be seen that the down line passes through the galvanometer to the central point of the key. The key at rest affords a path, via its back stop, through the sounder to the up terminal. When depressed, the battery is connected positive to down and negative to up, the sounder being cut

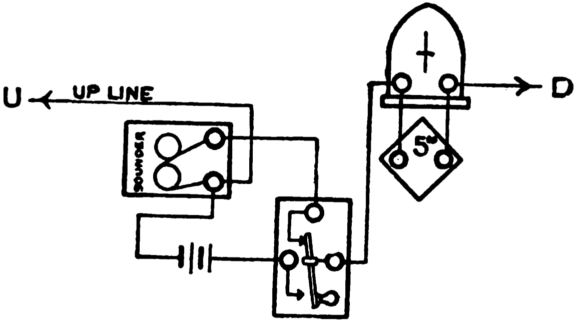


FIG. 89.—Direct sounder connections.

out of circuit by the severance of the connection between the key and the backstop. The galvanometer indicates the current sent or received. Its terminals are joined by a 5^{ω} resistance coil for the purpose of reducing the resistance which its insertion unshunted would entail. As the current employed for working a direct sounder is very large the presence of the shunt does not prevent a satisfactory deflection being obtained.

INTERMEDIATE STATIONS.

The connections necessary to join up three sets upon a circuit are indicated in Fig. 90. At the up station the up line terminal of the set is earthed and the down line terminal is connected to the down line, *i. e.* the line to the down station. It is important that this fact should be clearly remembered because the statement applies to nearly every type of apparatus. At the intermediate station the down line terminal is connected to the down line and the up terminal to the up line. At the down station the down terminal goes to earth, whilst the up terminal goes to the up line. It will be noticed that at an up station the line is called a down line, whilst from the point of view of the down station it is an up line.

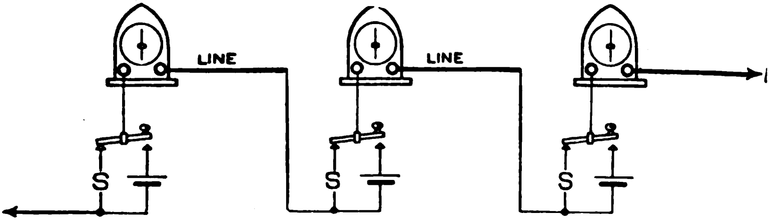


Fig. 90.—Three direct sounders upon one circuit.

PATH OF CURRENT.

The path of the current when the intermediate station depresses his key is from the positive pole of his battery, to centre of key, through the galvanometer, along the down line, through the down sounder, along the key, through the down galvanometer through earth, through the up sounder, along the key, through the up galvanometer, along the up line, back to the negative pole of the battery. Both sounders and all three galvanometers are affected. The path from the other stations is similar and should be sufficiently obvious. It may be remarked that the terms up and down line are employed above because the intermediate office was under consideration and the terms are relative to that office.

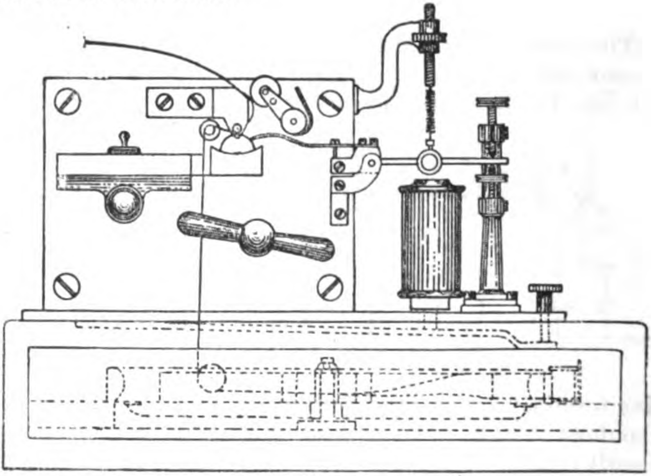


FIG. 91.—Local inker.

The current required to work a direct sounder circuit is 90 to 100 m.a. and No. 1 cells should be employed. The resistance of the galvanometer described on page 186 is 30$^{\omega}$, and with the 5$^{\omega}$ shunt gives a joint resistance of 4$\frac{1}{2}^{\omega}$. The direct sounder was employed where the total resistance of the circuit (apparatus included) did not exceed 200$^{\omega}$.

THE DIRECT WRITER.

The direct writer, printer, or inker, as it is variously termed, comprises an electromagnet with an armature which, when actuated, causes a revolving disc immersed in an ink-well to be brought into contact with a paper tape moving at a uniform speed (see Fig. 91). The mechanical portion of the apparatus consists of a spring driving a train of wheels, which revolve the inking wheel in a direction opposite to that in which the tape is carried past it. The tape passes between two barrels, one of which is free to move and presses upon the tape, the other being revolved at a uniform speed by the train of wheels. A governor is employed for securing the uniformity of the rate at which the tape moves forward, and a brake is provided for stopping the instrument when not in use. Two screws limit the play of the armature and inking disc in an upward and downward direction. These adjustments are made almost entirely from the point of view of securing clear inking marks, whilst the sensitiveness is varied by a screw which bodily raises or lowers the electromagnet as a whole. The armature usually consists of a soft iron tube split longitudinally to prevent the instrument being rendered sluggish in action by reason of the eddy currents which would otherwise be induced in the armature. It is, however, open to question whether this provision is really necessary.

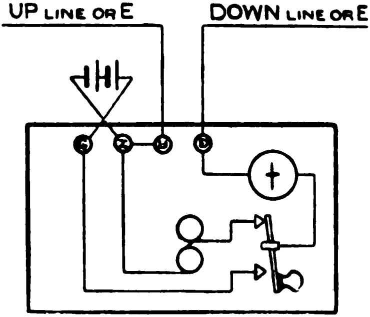


FIG. 92.—Direct writer connections.

The connections of the direct writer (Fig. 92) are similar to those of the direct sounder, but the battery and up and down line terminals are separately mounted upon the base of the instrument. The instrument illustrated in Fig. 91 is a local inker, and is sometimes used upon relay worked circuits. The direct writer is similar, but contains a key and galvanometer upon the same base. The connections between line and earth are determined in the manner previously detailed. The electrical portions call for no comment.

The resistance of the electromagnet of a direct writer is 300^{ω}, and the galvanometer, which is of a simple form, about 30^{ω}. The current required is from 15 to 20 m.a.

It should be noted that where a direct sounder is employed at one end of a circuit and a direct writer at the other, the battery power required will be different, on account of the differing values of current required to work each form of instrument.

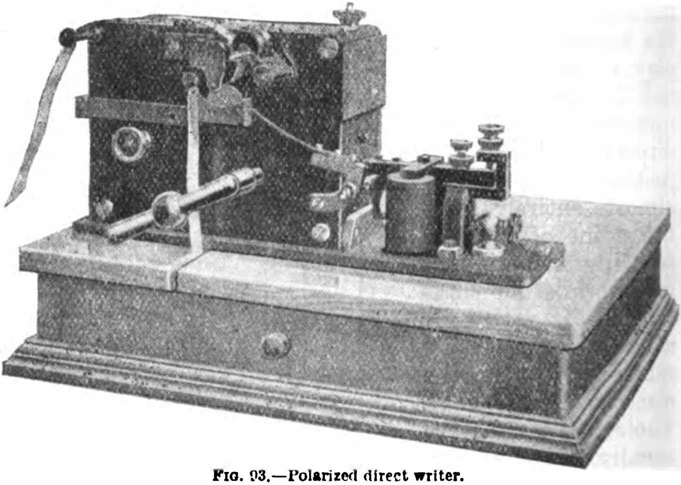


Fig. 93.—Polarized direct writer.

The figure of merit of the electromagnet is 4·9 m.a., and 10 m.a. for the galvanometer, with which current a deflection of a quarter of an inch should be produced. The speed of the slip should be from six to seven feet per minute.

POLARIZED INKER.

This instrument (Fig. 93) is a combination of a polarized sounder and inker. It is differentially wound to a resistance of $500^{\omega} + 500^{\omega}$ and requires a current of 10 m.a. for double current, and 15 m.a. for single current working.

The signals on the sounder are then loud enough to read by sound—a condition not provided by the inker previously described.

OPEN AND CLOSED CIRCUIT WORKING.

There are two methods of working circuits respectively known as the open and closed circuit methods. The direct sounder circuit may be taken as a typical open circuit method since the battery is not normally connected to the line, and in such circuits it will be obvious that a battery must be provided at each office on the circuit. A typical closed circuit method, a method very largely used in the Colonies and America, is illustrated in Fig. 94. The current is normally flowing through the circuit when idle, and signalling is effected by opening the two-way switch attached to the key, thus permitting the circuit to be made and broken, in accordance with the movement of the key. The sounders are, of course, in the main circuit in series with the battery which may wholly be located at any one of the offices or may be distributed. The signals sent out are also heard upon the sounder at the sending station, and it is contended that this makes for better sending. In America this provision is almost universal.

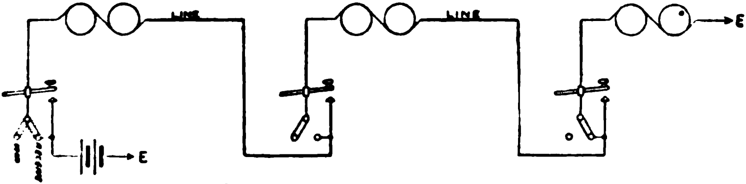


FIG. 94.—Closed circuit system (intermediate office signalling).

With a number of stations upon one circuit there is only one battery, instead of one battery per station, to maintain, and this single battery may be located at the most convenient point. Places difficult of access by reason of infrequent railway service or which can only be reached by road, cause the labour cost of maintaining batteries to be very high. It will therefore be recognized that the waste of energy due to the single battery supplying current when the circuit is idle will be more than counterbalanced by saving in the cost of maintaining a similar but lightly worked battery at each office. Where secondary cells are used at the main station the saving is still greater.

The only other disadvantage is that if a switch is left open the circuit is stopped until it is closed again. With the double current system a similar happening would not be serious since the key current could be balanced out by placing an equal opposing battery in the line. The British Insulated and Helsby Cables, Limited, have devised a system in which the Vyle polarized sounder is employed to obviate the use of the switch. The current (10 to 15 m.a.) passes through the single current key, via the back contacts, and the sounder is adjusted so that this current passing in the spacing direction lifts the armature. Depression of a key stops the current, and the armature descends by magnetic attraction.

There is one other point to be considered, and that is, that as compared with single current open circuit working, the closed circuit method gives greater constancy of adjustment. The batteries at each station may differ somewhat in E.M.F. and, on account of varying insulation, the current received at any particular office may differ according to which station is signalling, thus entailing different regulation. This difficulty does not exist with the closed circuit method, since the current, whatever may be its value, is invariable. Again, the use of the double current system obviates the difficulty.

The value of the current received at the end of a long line is, by reason of leakage, often very much less than the current sent out, and on a long closed circuit, were the battery located at the terminal office, it might readily happen that when the power was increased sufficiently to provide a good working margin at the far end, its value at the sending end would be dangerously or extravagantly high. This is why on a long line it is usual to distribute the battery between various selected stations *en route*.

The closed circuit system used in connection with the London Intercommunication Switch is a closed circuit system suitable for comparatively short lines where the minimum expenditure of energy on the current flowing normally has been secured. The central battery telegraph system is another closed circuit method, but in this system there are all the advantages gained by the continuous current without appreciable wastage of energy.

THE SINGLE NEEDLE SYSTEM.

The single needle instrument, although contained in a single case, may be divided into two distinct parts, the commutator or transmitting keys and the coils. The coils are a special form of galvanometer, and serve to indicate the direction of the current. The commutator, when at rest, completes the circuit of the coils from line to earth, whilst the depression of a key puts the battery in circuit in a direction dependent upon which of the two keys is depressed.

The two coils of the instrument are of rectangular shape placed side by side, and held in position upon the brass support by clamping screws. The coils are wrapped as closely round the needle as possible in order to concentrate the magnetic field produced by the current.

The two patterns of needle coils in use at the present time are Varley's and Spagnoletti's, all new instruments being of the latter type. The difference in the two types lies in the shape and in the method of rendering the needles magnetic by induction from fixed permanent magnets. In the early forms of single needle the magnetic needle was a permanent magnet, but it was found that the passage of the working currents in course of time weakened the small magnetic needle, and frequently, after a thunderstorm, the needle was even reversed in polarity by the small portion of the lightning discharge which sometimes passed through the coils. It was to avoid this difficulty that the induced needle was introduced.

VARLEY'S COILS.

In the Varley form the needle is a fork-shaped piece of soft iron rendered magnetic by induction from a pair of comparatively large bar magnets fixed one upon each coil (Fig. 95).

The magnetic needle is fixed upon an axle, which also carries the pointer, and is suspended well above the centre of the coils. As the direction of the magnetic field due to the earth (vertical component) is in such a direction as to make the upper end of the soft iron needle South, and the lower end North, the permanent bar magnets are arranged so as to reinforce instead of to oppose this effect. The upper or fixed end of the needle is therefore of South and the lower ends North polarity. The passage of a current through the coils creates a magnetic field through the centre spaces, and the needle deflects in accordance with the principles previously explained. In this case, however, the deflection of the needle is opposed by the earth's *vertical* field (which is larger than its horizontal field), and also by gravity.

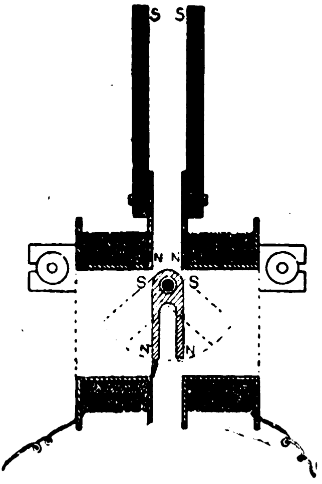


FIG. 95.—Varley's coils.

SPAGNOLETTI'S COILS.

The Spagnoletti dial (Figs. 96 and 97) is fitted with two coils clamped in position in the same manner as in the Varley type, but here the resemblance ends. A pair of horse-shoe magnets is employed to polarize the soft iron needle, which is made in two sections magnetically separated by the layer of spelter which serves to braze them together. The two magnets, each of which passes over the coil from back to front, have their like poles opposite. The soft iron axle extends in a downward direction to form the lower half of the needle, which end is given North polarity by induction of the two North poles of the horse-shoe magnets upon the front part of the axle. In similar manner the upper end of the needle is made South. This needle is given a somewhat curious shape in order to secure a firmer impact upon the stop-pins, or sounding pieces as the case may be. The needle is also better balanced than in the Varley form. Similar remarks in regard to the direction of the current and the resulting deflection apply in this case also. A current from left to right causes the needle top to deflect to the right.

One end of each coil is connected to the brass bobbin upon which it is wound, and the other end is brought out to its terminal by a stout piece of spirally coiled silk-covered wire. There is therefore only one exposed wire connection for each coil, the current passing along the brass frame from one coil to the other.

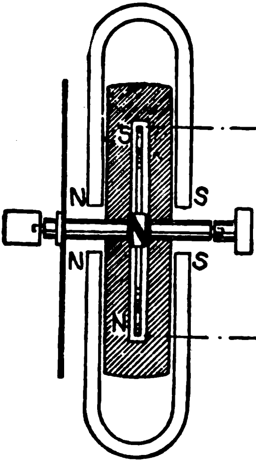


FIG. 96.—Side view of Spagnoletti's coils.

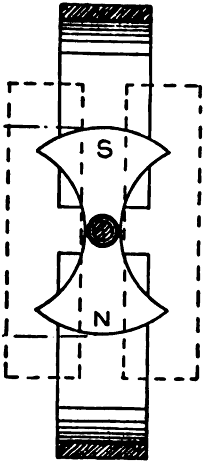


FIG. 97.—Illustrates the shape of the needle in Spagnoletti's coils.

These large horse-shoe magnets retain their magnetism for a very long period of time, in spite of the passage of the working signals. The demagnetization or reversal of the magnets by a lightning discharge is a very remote possibility, and one which need not in this case be seriously considered. The arrangement is, therefore, an excellent one.

Figure of Merit.

The coils are wound to a resistance of 200^{ω}, and have a figure of merit of 3·06 m.a. with which the needle should be deflected from a vertical position to either stop-pin. Good working signals can be obtained with 9·3 m.a.

In order to transform the needle from visual to sound working, the stop-pins are replaced by two pieces of specially shaped tin so arranged that the impact of the needle produces two differing sounds according to the direction of its deflection. This amply sufficed for the majority of sub-offices, but where a greater volume of sound was required Neale's acoustic dial was very frequently employed.

Neale's Coils.

Neale's dial (Fig. 98) consists of an electromagnet having its pole pieces P_1 and P_2 continued through the front of the dial, between which is pivoted a heavy soft iron needle rendered magnetic by induction from a curved permanent magnet *N S* placed at the back. The heavy upper half of the needle is of soft iron, whilst the lower part serves only to complete the needle, and is quite light in comparison with the other. The axle which holds the needle is provided with a small hook to which is attached a light spiral spring for the purpose of bringing the needle back after deflection. The other end of this spring is fixed upon a carriage (Fig. 99) which may be moved laterally by a screw upon the right, thus enabling the needle to be centred between its pole-pieces. The sounding pieces consist of tubes cut longitudinally and provided with extension pins upon which the needle strikes.

The use of an electromagnet in place of the coil of wire employed in the ordinary forms of needle dial gives a greater impact with the same value of current. This is entirely due to the use of iron and consequent improvement of the magnetic circuit.

COMMUTATOR.

The general appearance of the commutator is shown in Fig. 100, and it is most important that the various parts of the actual apparatus should be identified with the sketch of their connections. Unfortunately it is not possible to draw the key as it appears to the eye, and at the same time clearly show its internal connections.

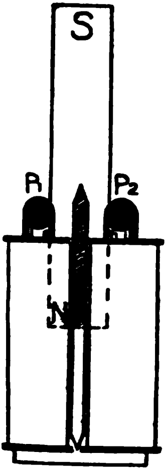


Fig. 98.—Neale's coils. Electromagnet and induced needle.

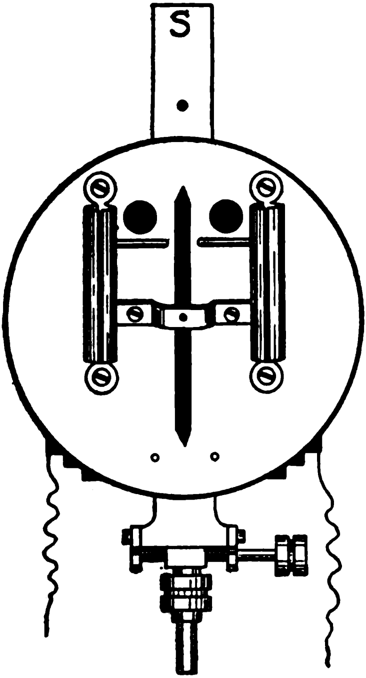


Fig. 99.—Front view of Neale's coils.

The commutator is furnished with six terminals, but when used in conjunction with the single needle two of these, *X* and *Y*, are permanently connected by a brass strap. These two terminals project horizontally at the back, and are connected to the backstops of the keys to which they are respectively opposite. The two outer terminals in front of *X* and *Y* are respectively connected to *Z* and *C* of the battery. The centre terminal *B* may be considered as the down line of the key, whilst the short front terminal *A* is always the up line terminal.

Each key is electrically divided into two parts, viz. the brass lever at the back and the front contact screw. The wooden part of the key is fixed to the brass lever, and the front contact screw is fixed to the wooden key itself.

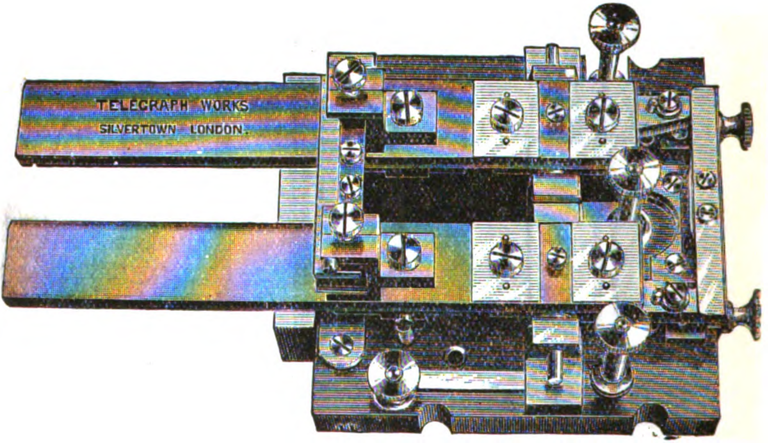


Fig. 100.—Commutator used with single needles and double plate sounders.

Upon depressing the key the front contact screw comes into contact with the "zinc spring," and the brass lever at the back rises from the back stop and makes connection with the "copper spring." The terms zinc and copper springs are expressive, and should tend to fix the functions of the various parts of the key in the memory. The right-hand brass lever is connected to the up line terminal, whilst the left goes to *B*. The only connections remaining to be dealt with are those of the front contact screws. These go to *X* and *Y*, the left to *Y* on the right, and the right to *X* on the left. This connection is made by the spiral of bare wire (see the right key) through the base of the instrument, these two connections being the only ones which the base conceals.

The connections are conventionally shown in Fig. 101. The keys are turned upon their sides, and movement to the left is equivalent to depression. The two contacts upon the right of the levers represent the copper bar, whilst the two front contacts represent the zinc bar.

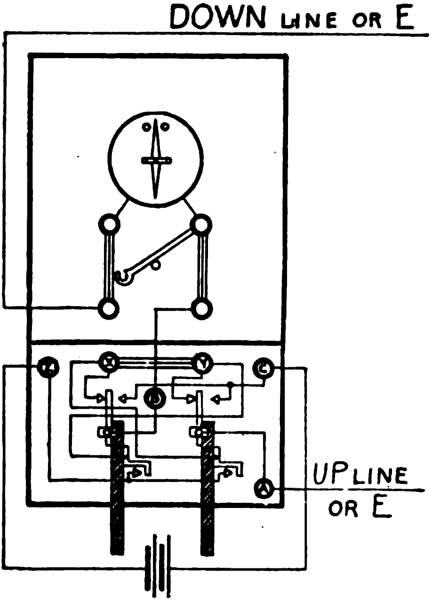


Fig. 101.—Connections of single needle.

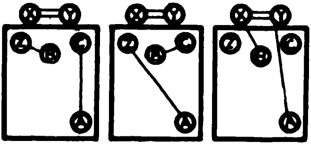
In the normal position a current entering at the up line terminal (usually marked *A*) goes to the centre of the right lever along its length through the *Y* back stop to *Y* along the connecting bar to *X*, through the *X* back stop down the left lever to *B*. The connections are therefore *A* to *Y* and *B* to *X* through the two back stops.

Depression of the right key causes the right lever to break with *Y*, and to make contact with the copper spring, whilst its front contact screw makes contact with the zinc bar. The positive pole of the battery is therefore connected to *A* and the negative to *X*, through the *X* back stop, along the left key to *B*. The connections are therefore *C* to *A* and *Z* to *B*.

The left key when depressed causes the left lever to break connection with the *X* back stop, and to make contact with the copper spring, so connecting *C* to *B*. At the same time the front contact screw makes contact with the zinc spring, thus connecting *Z* to *Y*, through the *Y* back stop down the right lever to *A*. The connections are therefore *Z* to *A* and *C* to *B*.

Each contact point is, of course, tipped with platinum. The play of the key is regulated by means of the front contact screw, which is securely held by means of the transverse screw, seen upon the right key in Fig. 100. (Compare also Fig. 87.)

SKELETON CONNECTIONS OF COMMUTATOR.



RIGHT KEY DEPRESSED LEFT KEY DEPRESSED AT REST

FIG. 102.--Skeleton connections resulting in each position of the keys.

The skeleton connections in each position of the keys, shown in Fig. 102, should be memorized. The following facts may perhaps be useful—(*a*) Right key sends copper to up line, (*b*) at rest *B* and *A* go respectively to *X* and *Y*.

CONNECTIONS OF SINGLE NEEDLE CIRCUITS.

The commutator and the dial are joined up in series so that every current which is sent out passes through the sender's instrument. The right-hand side of the coils is joined to *B* whilst the left side forms the down line terminal of the set, *A* being the up line terminal. To prove the connections, the up and down terminals of the set should be connected. Remembering that the right key sends copper to up and that the deflection is in the direction of the current through the coils, it will at once be seen that *B* must go to the right (see Fig. 101) of the coils in order that the current may go through from left to right when the right key is down.

Three offices connected by two lengths of line are illustrated in Fig. 103, and the up and down instrument terminals have been clearly indicated. The joining-up of the set then follows the rules laid down in the case of the direct sounder.

(1) Up station, up line terminal to earth, down line terminal to down line.

(2) Down station, down line terminal to earth, up line terminal to up line.

(3) Intermediate station, up line terminal to up line, down line terminal to down line.

The path of the current and its effects in any given position of any of the keys is fairly obvious, and one example will suffice. Let the intermediate station depress the right key; the current flows from the positive pole of the battery, to up line terminal, to line through the up dial (left to right therefore deflecting it to right) to *B*, to *X*, to *Y*, to *A* (up line terminal), through earth to down line terminal of down set through the dial (deflects to right) to *X*, to *Y*, to *A*, along the line, through the intermediate station's coils (needle deflected to right) to *B*, to *Z* and so back to the battery.

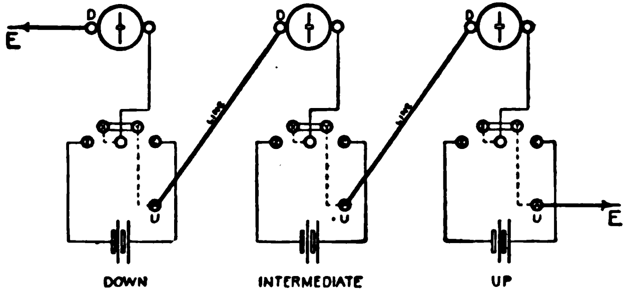


Fig. 108.—Three single needle stations upon one circuit.

Resistance and Battery Power.

The resistance of the instrument is always 200^{ω} no matter which type of dial is employed, and a current of from 15 to 20 m.a. is provided for actual working. The type of cell employed to work such circuits is the Leclanché No. 3 size.

ADVANTAGES OF SYSTEM.

The single needle system presents the advantage that many offices may be grouped upon a single circuit. Upon such circuits the value of the current received at any one of the offices may differ according to which office is sending. This is, of course, especially noticeable upon long circuits due to changes in insulation resistance, but as the system is rarely employed on any but short circuits, this difficulty does not assume serious dimensions. Another cause producing variations in the value of the received current is the condition of the various batteries; at one office the battery may be at its maximum E.M.F., at another it may be at the minimum, whilst the batteries at the remaining offices are in conditions which respectively vary between the two limits. The reason for the excellent behaviour of a single needle system under such conditions lies in the fact that residual magnetism does not come into play.

RELAYS

A relay may be defined as an electromagnetic device which either forms or breaks an electrical connection by the motion of its moving system produced by the passage of a current through the coils. Its prime purpose in telegraphy is to economize battery power, thereby obviating the use of extremely high voltages for working long circuits. The current is employed to direct and control the movement of a contact arm which joins up a battery at the receiving end of the circuit, and it is this battery which produces the actual signal.

Relays may be divided into two distinct classes (1) non-polarized and (2) polarized. In a non-polarized relay the direction in which the armature or armatures move is independent of the direction of the current passing through its coils.

RELAYING SOUNDER.

An example of such a relay is the relaying sounder (formerly termed an uprighter or uprighting sounder).

This instrument is typical of the many varying forms which the non-polarized relay takes in different circumstances.

The relaying sounder consists of an electromagnet with its armature mounted upon a brass lever playing between an upper and lower contact point. It differs from an ordinary sounder in the shortness of its electromagnet, in the lightness of the armature lever, and in the provision of the platinum tipped contact points. The proximity of the armature to the cores when the former is depressed may be adjusted by means of the lower contact screw, which can be raised or lowered as required. The upward play is similarly adjusted by the upper contact screw, whilst the tension may be suitably varied by the screw which is to be seen at the front of Fig. 104.

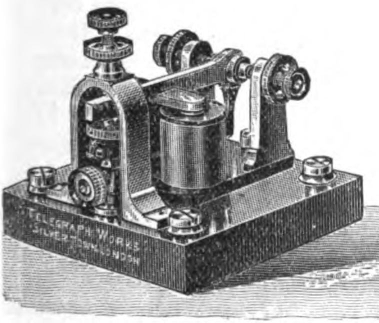


FIG. 104.—Front and side view of relaying sounder.

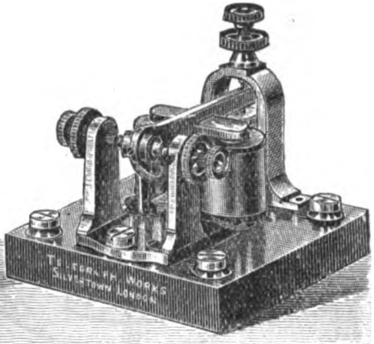


FIG. 105.—Back and side view of a relaying sounder.

Normally the lever joins the upper contact, but when actuated, the lower one. A current in either direction, provided it be of sufficient strength, draws down the armature.

The coils and shunt of the "relaying sounder B" have resistances of 40^{ω} and 500^{ω} respectively. The figure of merit is 69 m.a. and the combined resistance 37^{ω}. The latest type of instrument has a joint resistance of 40^{ω} and is termed the "relaying sounder 40^{ω}." Its coils and shunt are respectively 44^{ω} and 440^{ω}. It may be added that the object of the shunt is to prevent sparking at the relay points (see page 221).

P.O. Non-Polarized Relay "B."

The Post Office non-polarized relay "B" bears a considerable resemblance to the standard relay (see Figs. 111

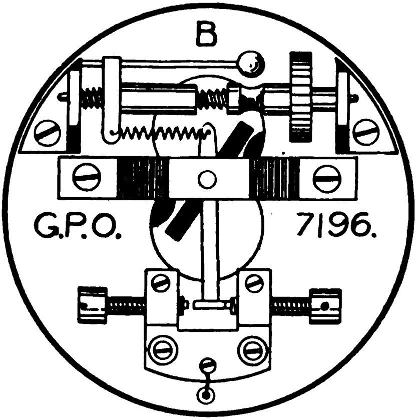


Fig. 106.—Top of a P.O. non-polarized relay "B."

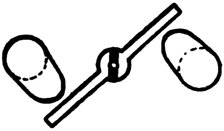


Fig. 107.—Plan of top armature and coils.

and 113), but its two soft iron armatures are not induced magnets. The two electromagnets are placed side by side, but with their polepieces deflected so as to include the armatures in the magnetic circuit from core to core. The arrangement will be sufficiently apparent from the plan of the top of the instrument (Fig. 106). The tongue is held to the right contact point by a spring and a current passing through the coils in either direction causes the armatures to be attracted against the force of the spring, and the tongue leaves the right contact point and goes over to the left. This arrangement is adopted for quadruplex working (Chapter IX).

The relay is differentially wound and an equal current flowing from *D* to *U* in one coil and *U* to *D* in the other, or *vice versa*, does not magnetize the cores of the relay. A current flowing in either or both coils from *D* to *U* or *U* to *D* magnetizes both cores and attracts the armatures. If the top of the left core is North the top of the opposite core is South, and therefore the magnetic circuit is from core to core through both armatures. These armatures are each divided in the centre by a layer of spelter which brazes the two halves together. This device prevents the armatures from becoming more or less permanently magnetized, since the demagnetizing force in such short lengths of iron as the two halves of each armature is considerable (see page 176). Moreover, the proximity of the armature to the cores and the consequent reduction of the air-gaps produces conditions favourable for considerable values of residual magnetism, were it not for the magnetic separation of the armatures. These breaks in the magnetic circuit tend towards the production of rapid and complete demagnetization of the cores.

The non-polarized relay "C" is similar to the "B" relay, but of larger dimensions. By increasing the quantity of iron in the magnetic circuit a greater working range is obtained. The resistance of its coils is $100^{\omega} + 100^{\omega}$

The B relay will work with a current of 6 m.a. and can be biassed against 15 m.a., whilst the C relay will work with 4½ m.a. and may be biassed against 10 m.a.

Relays Used in Telephony.

The relays which form so important a part in a large telephone exchange differ very widely from those previously described, although belonging to the same class, viz. non-polarized relays. Relays used for telephone signalling are designed from the point of view of reliability, compactness, and minimum cost, rather than from the point of view of sensitiveness and rapidity of action. Many of the relays have gravity controlled armatures, whilst pivots are avoided by allowing the thinned edge of the armature to rest in a nick or cut upon the base of the instrument. Such a relay is illustrated in Fig. 108, and it will be observed that the magnetic circuit is nearly closed. Since great rapidity of action is not required, this arrangement presents the advantage that the sensitiveness of the relay is thereby increased. The distance of the armature from the core when the relay is actuated is, of course, adjusted so that the relay shall not stick.

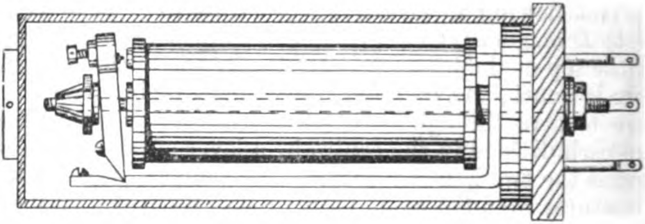


Fig. 108.—A type of relay used in telephone exchange systems and also in the Metropolitan intercommunication system.

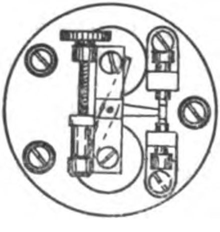


Fig. 109.—Translating relay used in connection with the London switching system.

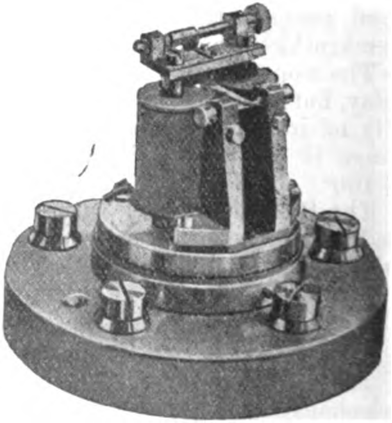


Fig. 110.—View of non-polarized relay D.

TRANSLATING RELAYS.

The relays (Fig. 109) employed in connection with the London switching system (Chap. XVI) upon the connecting cords are of practically the same pattern as those formerly used in the telephone permanent current system. The two armatures are placed between the four polepieces of the electromagnet, and are controlled by an adjustable spiral spring. The resistance of the instrument is 200_{ω}.

It may be noticed that the armatures are solid, and are not divided by a layer of non-magnetic material, as is the case with the relays used in quadruplex working. The dimensions of the various parts are also very much less.

POLARIZED RELAY.

Polarized relays may be defined as relays in which the direction of movement of the tongue depends upon the direction of the current. It is necessary to avoid the very commonly used and inaccurate expression "only marks with one direction of current," because a mark is made by both directions of current when used with the double-plate sounder (dash or dot according to the direction of the current).

Generally speaking, polarized are more sensitive than non-polarized relays. Also the armatures of non-polarized relays are usually unmagnetized soft iron, whilst those of polarized relays are either permanent or induced magnets. In other words, the armatures of non-polarized relays are not polarized, whilst those of polarized relays are.

P.O. STANDARD RELAY.

The P.O. standard relay consists of two electromagnets placed side by side, between the poles of which are two movable soft iron armatures, rendered magnetic by induction from a large horse-shoe magnet placed behind them. The instrument is shown in Fig. 112 with one of its electromagnets removed, and in skeleton perspective in Fig. 111.

The large horse-shoe magnet is bent round the coils so as to occupy the minimum space. For the reasons that obtained in the case of the inducing magnets employed in the single needle, the upper pole is South and the lower North. The corresponding polarity is therefore imparted to the ends of the soft iron armatures *s* and *n*. The axle which carries *s* and *n* also carries the contact arm, transversely tipped with platinum. Upon either side is fixed a platinum-tipped contact screw, and it is between these screws that the tongue plays.

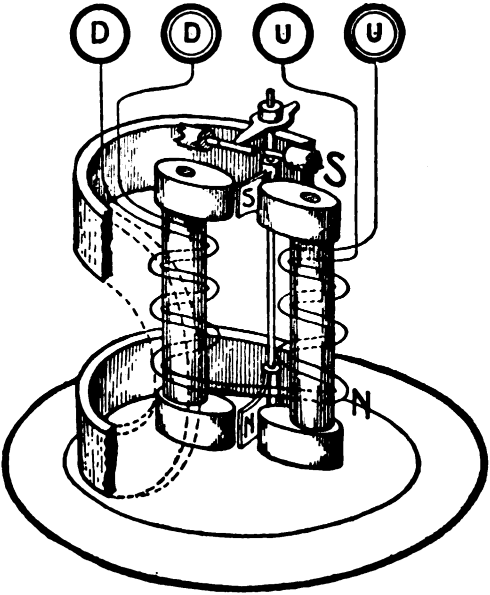
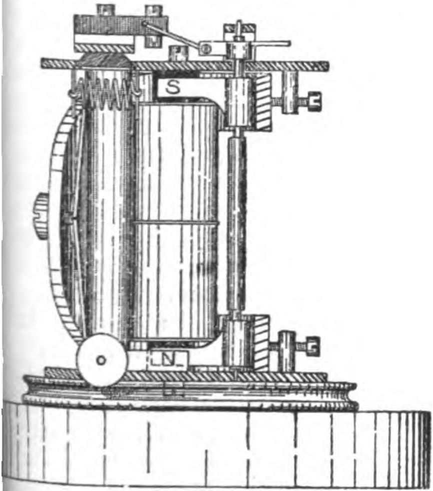


FIG. 111.—Principle of P.O. standard relay.

The instrument is differentially wound, *D* and *U* being the terminals of one coil, and *D*-circle and *U*-circle those of the other. A current passing from *U* to *D* or *U*-circle to *D*-circle makes the top of the left electromagnet South and the bottom North, whilst the top and bottom of the right-hand electromagnet are made respectively North and South. The armatures are therefore acted upon with four forces, being repelled by the left and attracted by right electromagnet. Reversal of the current reverses the direction in which the armatures tend to move. The two coils are equal in resistance, and with equal currents produce an equal effect upon the armatures. If a current is sent from *D*-circle to *U*-circle, whilst an equal one flows from *U* to *D* in the other coil, no effect is produced, since the two windings have an equal tendency to give the electromagnet opposite polarities.



112.—P.O. standard relay "B" (front coil removed).

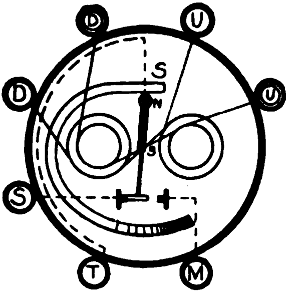


FIG. 113.—Winding and terminals of standard relay.

The general arrangement and directions of the windings are clearly visible in Fig. 111. A current passing from *D* to *U* or *D*-circle to *U*-circle causes the armatures to be held over to the left, whilst a current in the opposite direction sends the armatures to the right. The disposition of the terminals is shown in Fig. 113, from which it will be seen that a current from either *U* terminal to a *D* terminal causes *T* to make contact with ***M***, whilst a current

D to *U* brings *T* into contact with *S*. (*T*, *S*, and *M* are the first letters of the words tongue, space and mark.)

The tongue of the relay when stationary always rests upon the *S* or *M* contacts, and never permanently in a central position. The two contact screws *S* and *M* are fixed upon a carriage which can be moved at will by means of the regulating screw. In this way the proximity of the armatures to either electromagnet may be varied. When the armatures are exactly midway between the polepieces if the tongue is held in a central position between *S* and *M*, the relay is said to be neutral, and the tongue will stay upon either side when placed there. When the armatures are placed in this central position the forces of attraction towards the polepieces upon either side are equal, but the balance is far too fine to be practically maintained. The moment the armatures move in the slightest degree the balance is upset and the armatures move over to the nearer side.

A relay which is not adjusted to neutrality is said to have a marking or a spacing bias as the case may be. A spacing bias means that the tongue will return to *S* after being moved over to *M* by the passage of a current. In that case it will be clear that even when deflected to *M* the *armatures* must be nearer to the left than to the right-hand electromagnet. The most sensitive condition of the relay is when it has been set neutral, and the distance between *S* and *M* reduced to the smallest possible limits. Increasing the distance through which the tongue has to move reduces the working speed of the relay. The adjustments of the relay are therefore (1) bias, by means of the regulating screw; (2) play, by means of *S* and *M*.

P.O. STANDARD NEUTRAL RELAYS.

For use in connection with double-plate sounders, repeaters, etc., where it is necessary to produce an effect in both directions by movement of the tongue, two spiral springs are added. These springs, which are of course adjustable and fixed at right angles to the tongue, serve to hold it in a central position midway between *S* and *M*. In another form of instrument a light flat spring is fixed upon the end of the tongue, and by means of a screw the length of the spring between the end of the tongue and the point at which it is clamped may be adjusted at will. The longer the length of this flat spring the smaller is the force with which the tongue is restored to its central position, and of course the greater is the sensitiveness of the arrangement. In the simpler double-plate sounder apparatus this device is preferable to the older spiral spring arrangement on account of the greater simplicity of adjustment, but for high-speed working experienced relay clerks usually prefer the older form on account of the superior fineness of adjustment which can be obtained.

RESISTANCE AND FIGURES OF MERIT.

Standard relays both ordinary and neutral are of two types, the older or "A" and the newer "B" type. The A relay is rather shorter than the B, and its two coils are wound to 200^{ω} each, whilst those of the B type are wound to 100^{ω} each. Although the B relay has a lower resistance than the A type, its figure of merit is the same, viz. ·5 m.a. (coils in series).

The resistance of the A relay in series, *i. e.* between *D* and *U*-circle, with *D*-circle and *U* strapped, is 400 and in parallel, *i. e.* *D* and *D*-circle strapped, and *U* and *U*-circle strapped is 100^{ω}. The values in the case of the B relay under like conditions are 200^{ω} and 50^{ω} respectively. To produce the same effect upon the tongues as 10 m a. through one coil requires 5 m.a. through the two coils in series, or a total current of 10 m.a., *i. e.* five in each of the two coils when joined in parallel. The figure of merit of a relay with its coils in parallel is therefore twice that with the coils in series.

BAUDOT RELAY.

The general arrangement of the relay is indicated in Fig. 114. Two large permanent magnets are united at each pole by a soft iron pole-piece carrying a steel point. Upon these points there rests an axle carrying the contact arm and the soft iron armature. The axle is divided into three parts by the interposition of a section of copper or brass between the soft iron ends. In this way the ends of the armature are induced with like polarity, and the contact arm moves in accordance with the direction of the current flowing through the coils of the electromagnet.

One of the bearings of the axle is a plain cone, whilst the other is a lengthened inverted V, and both are detachable for cleaning. The pull of the permanent magnets on the axle serves to hold it in position. The two limbs of the electromagnet can be raised or lowered separately by means of two screws and guides, which are provided to ensure that the coils shall always remain parallel to each other.

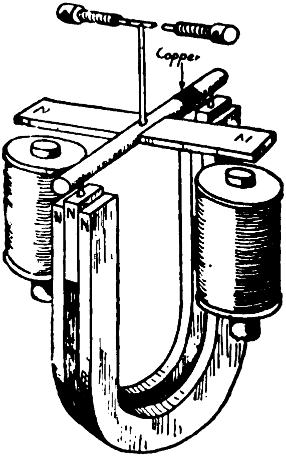


FIG. 114.—Principle of Baudot relay.

The instrument (Fig. 115) is usually wound to a resistance of about 200^{ω}. It possesses the advantage of light moving parts and a very wide range of adjustment. It is readily adjusted to neutrality and maintains this condition well, but it has been found that it possesses no advantage over the P.O. standard relay *B*. Its inductance is 1·26 henrys at 20 to 30 m.a.

TEST FOR DIFFERENTIALITY.

A relay is said to be differential when its two windings have exactly the same resistance, and have equal effects upon the cores when equal currents pass through them. The best test is obtained by joining up a battery and key to the relay, firstly between *D* and *D*-circle with *U* and *U*-circle strapped, thus placing the coils in series, but in such directions that the relay should not be magnetized, and secondly by joining the battery and key between *D*-circle and *U* strapped together, and *D* and *U*-circle joined, thus placing the coils in parallel. If the relay is then unaffected by working the key, the relay is differential.

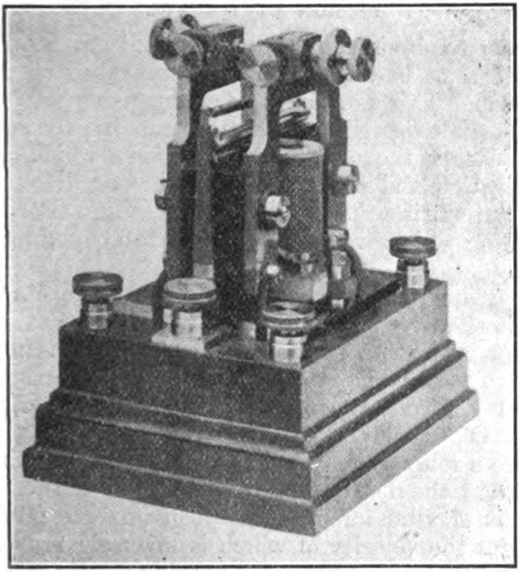


FIG. 115.—Baudot relay with cover removed.

In the first test, since the same current passed through the coils, it is proved that the windings have equal but opposite effects upon the cores with equal currents. The second test proves that the resistances of the two windings are equal, as otherwise one coil would carry more current than the other, and in view of the result of the first test would cause the relay to be affected.

DESIGN OF RELAYS.

In order to obtain rapidity of action, it has been shown that care must be taken to avoid large values of residual magnetism. This is accomplished by using iron of the softest possible description, and by arranging the magnetic circuit so that the molecular movements which produce magnetization and demagnetization are facilitated to the utmost extent, in other words by preventing the formation of anything which even approximates to a closed magnetic circuit.

It may be remarked *en passant* that the P.O. relay possesses the advantage of having two air-gaps as opposed to the one in the Siemens relay. This should, and no doubt does, tend towards more rapid and complete demagnetization, but it is not the real reason for the superiority of the Post Office relay.

Where a relay is required for high-speed working, the weight and the distribution of the weight of the moving system is of vital importance. A given force produces a movement the velocity of which is inversely proportional to the moment of inertia of the moving system. Now the moment of inertia is the mass of every particle of the moving system multiplied by the *square* of its distance from the centre line of the pivot. In the Siemens relay the moving system is heavy, and, what is far worse, extends far beyond the pivot. Compare this with the short armatures and light tongue of the Post Office relay, and the reason for greater rapidity of the newer instrument is at once apparent.

It will of course be quite obvious that for obtaining high speeds the angular movement of the tongue should be reduced to the lowest possible limits.

THE DOUBLE-PLATE SOUNDER.

The single needle, even when fitted with Neale's coils, proves unsatisfactory in any large instrument-room on account of the insufficient volume of the signals. Moreover, the raised writing-desk renders it unsuitable for fixing upon tables along with sounder sets, but of course this could be remedied by altering the design. The double-plate sounder meets both these objections, whilst the simpler single needle may still be employed at the distant and intermediate stations.

The present type of instrument is the result of evolution with Bright's Bells as starting point. In this arrangement the increased volume of signal is secured by the use of a relay and local battery. The function of the received current is therefore merely to direct and control the movement of the relay tongue, and this in turn determines which of the plate sounders is to be actuated. The relay employed is of the Standard Neutral type fitted with springs which normally hold the tongue midway between *S* and *M*. A current passing through the relay in the direction *U* to *D* causes the tongue to move over to *M*, whilst a current in the reverse direction causes *T* and *S* to be joined. Between *T* and *S* is connected the "dot" sounder and local battery, whilst *T* and *M* are joined by the "dash" sounder with the local battery also included. The arrangement of this circuit will be readily apprehended from a consideration of Fig. 116. When the tongue moves over to *S* the local battery sends a current through the left sounder, *S* contact point, along the tongue to *T* and back to the battery. Upon cessation of the current the spiral springs return the tongue to its normal position midway between *S* and *M*. Similarly a movement of the tongue to the right energizes the "dash" sounder.

PLATE SOUNDERS.

The plate sounders each consist of an electromagnet and pivoted armature, normally held away from its cores by means of an adjustable spiral spring. The difference in the sounds produced by the two sounders is due to the difference in the material composing the two plates, one being of brass and the other of steel. The sounders are fixed upon the inner sides of a sounder-screen mounted upon a turn-table; the remaining details of their construction will no doubt be apparent from Fig. 117.

COMMUTATOR.

The commutator is of the same pattern as that employed in the case of the single needle, but it is joined up in a slightly different manner. It will be remembered that the depression of either key joins up the battery between *A* and *B* in a direction dependent upon which of the two keys is used. The received current passes along the *XY* strap in the single needle, but in the double-plate sounder this strap is removed and the relay inserted. The single-needle dial is replaced by a single-current galvanometer, the left side of which forms the down line terminal of the set. The object of these alterations is to prevent the sent signals being received at the sending station and to provide an indication that currents are being sent out and received. Were the galvanometer not provided, a disconnection in the local circuit would pass undetected.

The objection to the reception of the signals at the sending end are the extra noise and the extra battery power necessary, against which no compensating gain in efficiency can be placed.

CONNECTIONS.

The full connections of a double-plate sounder station are shown in Fig. 116. With a single-current galvanometer substituted for the dial and *X* and *Y* unstrapped and respectively joined to *U*-circle and *D* of the relay the connections are identical with those of the single needle. It is useful to remember that the two connections between *X* and *Y* and the relay cross each other. *A* is the "up line" terminal, and the left side of the galvanometer the "down line" terminal. At an up office the galvanometer (*D* terminal) is joined to line and *A* (*U* terminal) earthed, whilst at a down station the galvanometer is earthed, and *A* is joined to the line.

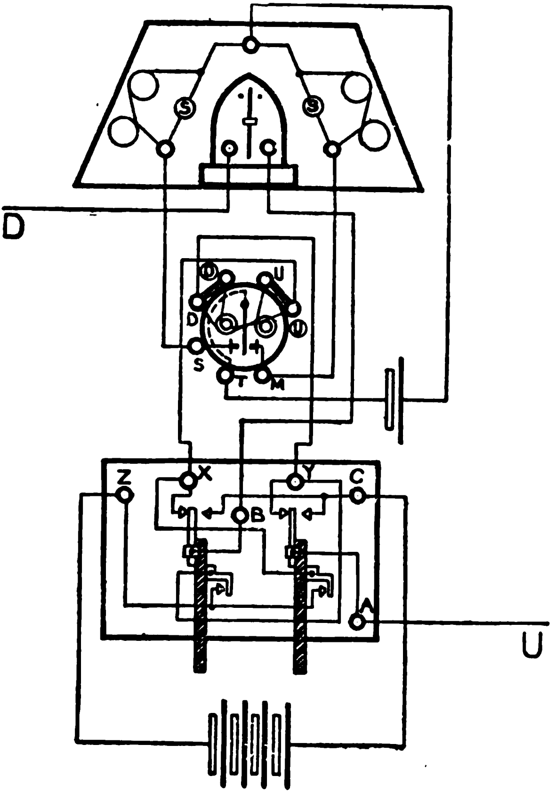


Fig. 116.—Connections of double-plate sounder.

The path of the current upon depressing the right key is as follows:—From positive pole of the battery to the copper spring, along the right lever, to *A*, to earth, through earth and by distant apparatus to line, along the line back to the up station through the galvanometer (deflecting it to the right), to *B*, to the centre of the left lever, through the *X* back stop to the right front contact screw, along the zinc spring back to the negative pole of the battery.

Depression of the left key joins the positive pole of the battery through the galvanometer to the line via the copper spring and left lever. The current passes through the distant apparatus to earth and thence back to *A*, right lever and back stop to *Y*, to the left front contact screw, and zinc spring back to the negative pole of the battery.

The path of the received current should be considered in relation to the distant station, which may be either a single needle or a similar instrument. It has been pointed out that the right key connects the positive pole of the battery to the up line terminal. At a down station this terminal is connected to line, and therefore the path of the current from the down station is from the positive pole of the battery along the line to the up station (represented by Fig. 116). It passes through the galvanometer from left to right (deflection to right), to *B* to the centre of the left lever through the *X* back stop to *U* and *U*-circle of the relay, through the two coils in parallel to *D* and *D*-circle (direction *U* to *D* causing *T* to go over to *M*), to *Y*, through the *Y* back stop, along the right lever, to *A*, to earth, and thence back to negative pole of the down station's battery. The relay tongue completes the circuit of the local battery through the right sounder, thus producing the "dash" signal required. If now the down station depresses the left key the direction of the current is reversed, thus deflecting both galvanometers to the left and actuating the up relay in the reverse direction. This causes *T* and *S* to be connected and the "dot" sounder actuated.

Up and Down Offices.

The fact that the apparatus connections between the up and down line terminals of the set are identical at up, down, or intermediate offices is of vital importance. It should be borne in mind that the difference in connections at these offices lies solely in the joining of the up and down line terminals to line and earth, or to up line and down line as the case may be. At an up station the up line terminal is joined to earth and the down line terminal to the line to the down station. At a down station the down terminal is earthed and the up line terminal connected to line. At an intermediate office the up line terminal is joined to the up line and the down line terminal to the down line. This applies to single needles, double-plate sounders, sounders—simplex and duplex—and Wheatstone sets. The apparatus connections are the same at every class of office, but the up and down line terminals are joined up in accordance with the above rules.

PREVENTION OF SPARKING AT RELAY CONTACTS.

The sounders are each wound to a resistance of 20^{ω} and each is shunted by a 500^{ω} resistance coil to prevent sparking at the relay contacts. The electromagnets have a considerable self-inductance, the effect of which is to oppose the rise of the current upon the making of the circuit. Upon breaking the circuit the sudden collapse of the lines of force due to the current cut through the windings and generates an E.M.F. in the same direction as that due to the battery. At the moment when the circuit is broken this E.M.F. adds to that of the battery, and the result is a spark. The shunt across the sounder provides a path for the current due to the E.M.F. of self-induction, other than that through the battery and slightly broken contact. The result is that the E.M.F. between the tongue and the contact point is reduced to a minimum, and sparking with its resultant wearing and roughening of the contacts is avoided.

ARRANGEMENT OF APPARATUS.

In all new double-plate sounders the galvanometer is fixed in the screen and the relay upon the table, instead of *vice versa*. The advantage gained is that the relay is more accessible for adjustment, and that the sounders and galvanometer can be simultaneously observed.

ADJUSTMENT

The adjustment of the plate sounders is similar to th of the ordinary sounder previously described. The tensi and upward play of the armature are limited by the r spective screws. The bobs which strike the sounding plat are screwed upon the armature lever, and their positio along the lever may be varied. The lever is inclined upwards, and consequently the position of the bob determine the proximity of the cores and armatures when depressed.

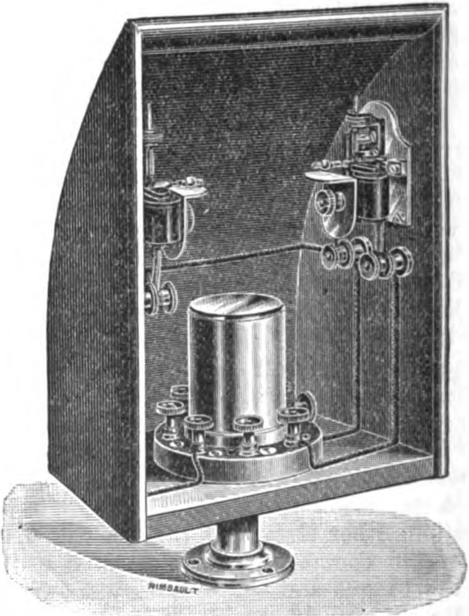


FIG. 117.—Double-plate sounder with the relay in the screen.

The condition of a battery varies, and its E.M.F. an internal resistance may have any value between the limit given on page 32. It will therefore be seen that th current through the sounders varies, which is the principa reason for the provision of adjustments. Very weak local batteries will require the tension to be very small and the play of the armature as limited as possible. The volume of the signals may then be increased by moving the ball to the outer end of the armature rod.

The adjustments of the relay are—(i) For neutrality. (ii) For play of tongue. (iii) For centring of the tongue. (iv) Tension of the springs.

When a relay is first sent out it is in a neutral condition when the spacing screw stands in the central position between the extreme limits of maximum spacing and maximum marking. If the relay is entirely out of adjustment the following procedure is recommended:—

(i) Remove the springs and then place the spacing screw in its central position, *i. e.* with an equal number of threads upon each side of the block.

(ii) Clean the contacts and adjust them until the relay is neutral and the required amount of play has been given. Then clamp the contact screws in position.

(iii) Put on the springs and adjust until the tongue is exactly midway with the least possible amount of tension.

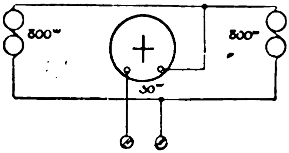
The object of the first operation is to ensure that the contact carriage is in the central position, thus allowing the spacing screw to be turned to an equal extent in either direction, should necessity arise. It is only by repeated improper alterations of the contact screws themselves that, with the relay in neutral condition, the carriage could be placed so far out of the central position that the spacing screw could only be turned in one direction.

It is recommended that in all cases of defective regulation the springs should be removed and the relay set neutral. The adjustment by passage of working signals is not so satisfactory, and frequently entails re-regulation after a comparatively short time. The play of the tongue should be as small as possible, but it is not wise to make the adjustment too fine. On the other hand, too much play seriously "clips" the signals.

If one of the spiral springs becomes loose, the distant sending produces a series of reversals. Defects in the local circuit reveal themselves during the adjustment for neutrality. Unless the defect in the regulation is quite obvious it is far better to entirely re-adjust the relay.

CURRENT REQUIRED.

The sounders have a figure of merit of 73 m.a., and are worked by a 2-cell No. 1. battery. The line battery consists of a sufficient number of No. 3 Leclanché cells to provide a current of from 14 to 17 m.a. with the relay in series.



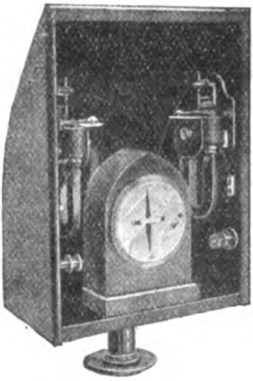


FIG 118.—Polarized double-plate sounder.

In Chapter II it was shown that the best method of joining up the coils of an electro-magnet was that which gave a resistance most closely approximating to the resistance of the rest of the circuit. With the "B" relay the coils should be placed in series when the total resistance of the circuit exceeds 150^{ω} (of which 50^{ω} is for the relay), and in parallel when less. With the "A" form of relay the coils should be in parallel only when the total resistance of the circuit is under 300^{ω} (of which 100^{ω} represents the relay). These rules also show whether it is more economical to provide 28 m.a. with a 50^{ω} or 100^{ω} relay resistance, or 14 m.a. with a 200^{ω} or 400^{ω} relay resistance.

THE POLARIZED DOUBLE-PLATE SOUNDER.

The two plate sounders, wound to a resistance of 800^{ω}, are polarized on the Vyle principle and joined in parallel. In this way the instrument becomes a directly worked one, the relay and local battery being dispensed with. A working current of 10 m.a. is required.

THE SINGLE CURRENT SOUNDER.

The object gained by employing the single current sounder, as opposed to the direct sounder, system lies in the economy of battery power which, under certain conditions defined later, results from the use of the relay-worked instrument.

The volume of the signals is independent of the value of the current received, and the relay permits a wider percentage variation in the current received before working is rendered impossible. Moreover, the use of the relay gives greater elasticity of adjustment.

CONNECTIONS.

The connections of the apparatus are shown in Fig. 119. The centre of the key goes to the left side of the single current galvanometer, the right terminal of which forms the down line terminal of the set. The positive pole of the battery is connected to the front stop of the key, and the relay is joined up in place of the sounder of a direct set. The down side of the relay goes to the back stop, and the up side forms the up line terminal to which the negative pole of the battery is also connected. If it is borne in mind that *U*-circle is the up line terminal the connections of the set

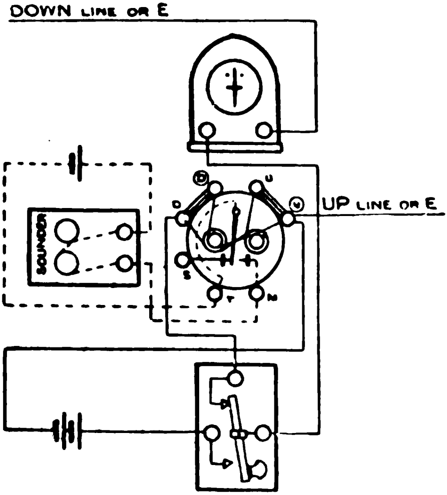


FIG. 119.—Single current sounder connections.

are readily remembered. The sounder and local battery are joined up between *T* and *M*.

The relay is given a distinct spacing bias, which should be sufficient to return the tongue smartly to *S* upon the cessation of the current, but which should not be so great as to cause clipping of the signals.

The set is joined up to line and earth in the manner previously described.* If the up station depresses the key a current flows from the positive pole of the battery through the galvanometer along the line to the down station through the down relay (direction *U* to *D*, causing *T* and *M* to be joined), through the back stop of the key, through the galvanometer to earth, and thence back to negative pole of the up battery. The current through the down relay causes the tongue to move over to *M*, thus completing the circuit of the local battery through the sounder. When the key is released the spacing bias reasserts itself and returns the tongue to the spacing side, so ending the mark.

ADJUSTMENT.

The armature of the sounder is sometimes allowed to approach very near to the cores in order to get loud signals from a weak local battery. A definite clearance should, however, always be maintained, and the remedy should always be applied at the point where the defect exists.

COILS IN PARALLEL OR SERIES.

If the coils of the relay are placed in series a current of 15 to 20 m.a. is required, whilst in parallel 30 to 40 m.a. must be provided. The arrangement which requires the lesser battery is chosen. Precisely the same factor determines whether direct or relay-worked sounder is to be employed.

The resistance of the B relay is so small that its coils should always be placed in series. With an A relay the coils should only be in parallel when the resistance of the line itself is under 170^{ω}.

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* If the reader has the least doubt upon this point he should refer back to page 189 and not proceed further until he has thoroughly grasped the principle.

Direct *v.* Single Current Sounder.

With 13 cells a direct sounder may be worked over 58^ω line resistance, whilst the same power employed for working a single current sounder would work through a line having a resistance of 140^ω with the A, and 340^ω with the B, type of relay.

Local Inker.

A local inker is sometimes used instead of a sounder, and occasionally it is joined in parallel with a sounder. The instrument (Fig. 91) is similar to the direct inker, but is minus key and galvanometer, and is wound to a resistance of 40^ω. A 500^ω resistance coil fixed inside the instrument is connected across the terminals of the electromagnet to prevent sparking at the relay contacts. Its joint resistance is 37^ω and its figure of merit 69 m.a. The speed of the slip should not be less than 6 feet nor more than 7 feet per minute.

Use of "D" Relays.

For reasons of economy many single current sounder circuits are worked with "D" relays, of the form illustrated in Fig. 110. The relay is furnished with a brass cover having a glass top. It is singly wound to a resistance of 200^ω, requires a current of 25 m.a., and costs about one-third as much as a P.O. standard polarized relay.

Use of Polarized Sounder.

The relay, local battery, and sounder in Fig. 119 may be replaced by a polarized sounder, the back contact of the key being joined to *D*-circle and the negative pole of the battery to *U*, which would then be the up line terminal of the set. The spring of the polarized sounder would be given suitable tension to raise the armature smartly on cessation of the current. A current of 15 m.a. with the coils in series (1000^ω) or 30 m.a. in parallel (250^ω) should be provided.

CHAPTER VII

CAPACITY, CONDENSERS, AND THE DOUBLE CURRENT SOUNDER.

CONDENSERS.

A CONDENSER essentially consists of two conductors separated by an insulating material termed, in this connection, the dielectric. The capacity of the condenser is the value of its charge or the quantity of electricity with which it is charged by unit potential difference (page 14). A condenser having a capacity of one farad would therefore be charged with one coulomb of electricity if a difference of potential of one volt existed between its terminals.

CAPACITY.

In order to appreciate the effects and behaviour of capacity generally, it is necessary to consider carefully the fundamental difference which exists between a conductor and an insulator. The former permits the passage of a continuous electric current through it, whilst the latter does not. Now the creation of a difference of potential between the two sides of an insulator (*e. g.* a slab of paraffin wax) produces an electric strain through it. In the case of the lightning protector it is clearly demonstrated (Chapter XX) that a large potential difference produces so great a strain upon the layer of air between the plates that the air breaks down, and a disruptive discharge occurs. Again, it is well known that a leyden jar may be broken into fragments by applying a sufficiently large difference of potential. The creation of a difference of potential between the sides of the slab of wax produces a strain, and a current flows into the dielectric at one side, and a current of equal value flows out at the other. This current ceases when the backward pressure of the dielectric is equal to the forward pressure of the battery, in other words when the backward E.M.F. of the condenser is the same as that of the battery. If the battery is removed and the terminals of the condenser are connected by a conducting path, the strain will relieve itself by discharging the quantity of electricity whose admission gave rise to the state of strain. This discharge is a current from the positive to the negative electrode of the condenser through the conducting path substituted for the battery.

ELECTRO-STATIC LINES OF FORCE.

The lines along which electric strains occur are termed electric or static lines of force, and a definite numerical value is assigned in a similar manner to that given to magnetic lines of force. A static line of force begins upon a conductor of higher potential and ends upon one of lower potential. In the case of a charged condenser they extend from plate to plate, and serve to mark out the direction of the electric strain and by their number express its value. There is a tension along their length, and they always endeavour to shorten themselves by an attracting pull between the two conductors to which they are attached. Parallel lines of force of similar direction exert a lateral repulsion upon each other.

ELECTRO-STATIC EXPLANATION OF CAPACITY.

Although the foregoing statement represents the simplest and easiest way of regarding the phenomenon of capacity, it may perhaps be well to give also the more conventional or electro-static explanation. Two insulated conductors may be thrown into opposite electrical conditions by means of a battery, influence machine, or other source of E.M.F. The conductor connected to the positive pole of the battery assumes a positive, and that connected to the negative pole assumes a negative potential, and when oppositely charged conductors are joined by a wire a current flows from the conductor of higher "electrical level" or "*potential*" to the lower, thus causing the bodies to regain their normal uncharged condition. The quantity of electricity which the bodies will contain depends upon the proximity, size, electrical pressure applied, and, lastly, upon the materials insulating them.

DIMENSIONS OF CONDENSERS.

Upon connecting a battery to a condenser a current flows until the difference of potential across the condenser is the same as the E.M.F. of the battery. If the battery is short-circuited the condenser discharges in the opposite direction to that of the current which charged it.

The capacity of a condenser depends upon its dimensions and the material of which the dielectric is composed. With a given thickness of dielectric between two metal plates of equal size the capacity is directly proportional to the area of either plate. The reason is that in doubling the area of the plates the area of dielectric strained is doubled, and therefore, since the difference of potential is the same between every part of the one plate and every part of the other plate, the quantity of electricity stored is doubled.

By doubling the thickness of the dielectric the capacity is halved if the size of the plates is unaltered. This is due to the greater stiffness of the thicker dielectric to an electric strain.

SPECIFIC INDUCTIVE CAPACITY.

If a number of condensers are constructed of precisely equal dimensions, but with different materials as dielectric, it will be found that their capacities will also differ to a considerable extent, the condenser in which the plates are separated by air having the smallest capacity. The values of the capacity obtained with the various materials substituted for the air dielectric are therefore stated relatively to the capacity of the air condenser, which is taken as unity. Since the *relative* capacities are always the same for the various materials, provided the condensers are of equal dimensions, the numerical values refer solely to the dielectric material. The numbers are those by which the capacity of an air condenser must be multiplied in order to obtain the capacity of the condenser when the material in question is substituted for air. The number assigned to each substance is termed its specific inductive capacity, or briefly its specific capacity.

The values of the specific capacity of a few materials commonly employed are given below:—

Material.	Specific capacity.
Air	1
Paraffin (solid) . .	1·9936
Paraffined paper . .	2·8
Shellac	2·74
India-rubber . . .	2·220 to 2·497
Sulphur	2·58
Ebonite	2·284
Gutta-percha . . .	2·462
Mica	5·5 to 8
Glass	3·013 to 3·258

The capacity of two copper wires of equal diameter and length covered with an equal thickness of gutta-percha and vulcanized india-rubber respectively will, if submerged, have relative capacities in the ratio of 2·462 to 2·497.

The capacity of a plate condenser varies directly as the area and specific capacity and inversely as the thickness of dielectric strained. Three metal plates separated by two dielectric slabs will give twice as great a capacity from the centre to the two outer plates as two sheets of metal separated by a single dielectric slab. The three-electrode condenser is clearly equivalent to two two-plate condensers joined together, thus doubling the area of dielectric strained, but with the same potential difference applied throughout. The capacity in microfarads of a condenser with two equal plates separated by a single sheet of dielectric is approximately :—

$$\frac{a \times k}{t} \times \cdot 000{,}000{,}2246$$

where *a* is the area of dielectric strained, *i.e.* the area of either metal plate, *k* is the specific capacity of the dielectric, and *t* its thickness in inches.*

CONDENSERS IN PARALLEL AND SERIES.

Condensers may be joined up in two different ways, viz. in parallel and in series, or cascade as it is sometimes termed. The latter method is very seldom if ever used in telegraphy, but it has a definite sphere of utility which will

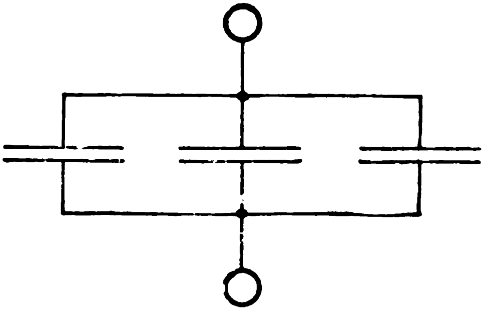

FIG. 120.—Three condensers in parallel.

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* The formula is obtained as follows :—

$$K \text{ (absolute electro-static units)} = \frac{a\,k}{4\,\pi\,t}$$

1 absolute electro-magnetic unit of capacity $= v^2$ static units where v is numerically equal to the velocity of light, viz. 3×10^{10} c.m. per second.

10^{15} m.f.s = 1 absolute electro-magnetic unit of capacity.

$$\therefore K \text{ in m.f.s} = \frac{a\,k \times 10^{15}}{t \times 4 \times 3{\cdot}1416 \times 3^2 \times 10^{20}}$$

$$= \frac{88{\cdot}42\,a\,k}{t \times 10^9} \text{ where } a \text{ and } t \text{ are in cms.}$$

$$= \frac{88{\cdot}42 \times 2{\cdot}54^2 \times a\,k}{t \times 2{\cdot}54 \times 10^9} \text{ where } a \text{ and } t \text{ are in inches.}$$

be apparent when the question of joint capacity has been considered. The two methods are illustrated in Figs. 120 and 121.

When condensers are joined up in parallel it will be quite evident that the effect is to increase the area of dielectric subjected to strain, and therefore that the resultant or joint capacity of the combination is obtained by adding their capacities together. In the case illustrated, in Fig. 120 if the respective capacities are 5 m.f., 2 m.f., and 1 m.f., the joint capacity is $5 + 2 + 1 = 8$ m.f.

Three condensers are depicted in Fig. 121 joined in series or cascade, and the joint capacity is then less than that of the smallest condenser. This is due to the greater thickness of dielectric interposed between the two extreme outside plates, since each condenser placed in series interposes the thickness of its dielectric in the direction of the electric strain.

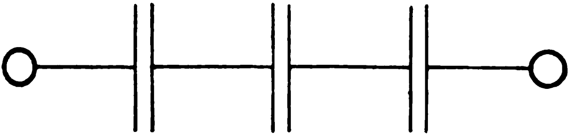

FIG. 121.—Three condensers in cascade or series.

The joint capacity of condensers in series is ascertained in the same manner as that of circuits placed in parallel. It is equal to the reciprocal of the sum of the reciprocals of the separate capacities. Taking the same values as before, viz. 5 m.f., 2 m.f., and 1 m.f., respectively :—

$$\text{Joint capacity} = \frac{1}{\frac{1}{5}+\frac{1}{2}+\frac{1}{1}} = \frac{10}{17} \text{ m.f.}$$

In the case of two condensers placed in *series* the above rule may be simplified in the same way as that for two circuits in *parallel*, viz. : that the joint capacity of two condensers in series is equal to their product divided by their sum. Similarly, if condensers of equal capacity are connected in series the joint capacity is equal to the capacity of one of them divided by their number.

Example.—(*a*) What will be the joint capacity obtained by connecting a condenser of 5 m.f. in series with one of 3 m.f. capacity? (*b*) Find the joint capacity of five 2 m.f. condensers joined in series.

$$(a)\ \frac{5\times3}{5+3} = 1\tfrac{7}{8} = 1{\cdot}875 \text{ m.f.}$$

$$(b)\ \frac{2}{5} = {\cdot}4 \text{ m.f.}$$

DIELECTRIC FOR CONDENSERS.

The choice of materials for use as dielectric in telegraph condensers is extremely limited. Glass is too fragile for use in extremely thin sheets, and by sufficiently increasing the thickness the size and cost of the condenser are enormously enhanced. Gutta-percha can be made in very thin sheets, but unless kept under water it rapidly becomes hard and brittle. Mica would certainly be an ideal substance, were it not for the fact that its cost prevents its use in any but standard condensers. For telegraph purposes paraffined paper is exclusively employed with entirely satisfactory results.

CONDENSERS USED IN TELEGRAPHY.

Formerly, telegraph condensers were built up of alternate sheets of paraffined paper and tinfoil, two sheets of paper being used to separate the adjacent sheets of tinfoil. The two top corners of every paper were cut off, but only one corner of each foil was removed. As the foils were laid alternately with their whole corners in opposite directions, it will be obvious that the corners of foils 1, 3, 5, 7, etc., projected beyond the papers upon the one side, whilst foils 2, 4, 6, 8, etc., upon the other, thus affording a simple and obvious method of connection. The whole series was held in position by two iron plates of rather larger size than the paper, and securely bolted together at the corners.

The method of condenser manufacture now in use by the Post Office is based upon the process introduced and patented by G. F. Mansbridge in 1900, by means of which the cost of building condenser plates has been very materially decreased. This process consists in the use of the material known as "tinfoil paper," in place of the metallic foil and plain paper previously employed. The tinfoil paper for making condensers is prepared in the form of continuous reels, and the process of making a condenser plate consists simply in winding up into the form of a flat roll two strips of this paper, each strip being perhaps 30 feet long, the precise length depending, of course, upon the capacity of the plate required. The tinfoil paper, which is somewhat similar to the paper used commercially for wrapping up packages of tea, etc., is prepared by pasting tin which has been reduced by chemical processes to a state of extremely fine subdivision, upon one side of a thin "body paper." To render this coating of tin paste practically continuous, and to improve its electrical conductance, the prepared paper is subjected in the course of manufacture to a calendering process, which consolidates and burnishes the minute particles of tin, and firmly fixes the metal to the body paper. It will be obvious that when two spirals of such paper are rolled up together the thin film of tin on one spiral will be separated from that of the other spiral by means of the paper which forms the dielectric. To obtain very high insulation, and to increase the dielectric strength it is usual to interleave between the strips of tinfoil paper a strip of thin plain paper, *i. e.* two strips of tinfoil paper, and two strips of plain paper are arranged alternately and rolled up together. The coating of tin on the tinfoil paper is so extremely fine that it would not be possible to make a soldered electrical connection to it, consequently the "lugs" by which contact is maintained consist of strips of thin metal foil laid between the foiled surfaces and the interleaving paper, separate lugs being of course used for the two foiled surfaces. After being removed from the winding machine the rolled strips are thoroughly desiccated by prolonged heating at a temperature of about 200° F., and the last traces of moisture are then extracted by means of desiccation under vacuum. When thoroughly dry and still in vacuo, hot paraffin wax is allowed to flow into the vacuum pan, and after the plates have soaked for some hours so that the wax may thoroughly penetrate the pores of the paper, the vacuum is broken, the wax is drained off, and the plates are then taken out and put under considerable pressure until cold. They are then tested for capacity and insulation. Obviously the value of the capacity can be adjusted by peeling off some of the outside layers to reduce the capacity, or by re-soaking the plate and subjecting it to a greater pressure to increase the capacity. The standard plate is of the 2 microfarad size, and this contains 21 square feet of surface to each electrode. The dimensions of a finished 2 m.f. plate are 7½ inches × 4½ inches × ½ inch thick, and its average weight is 13 ozs. The specific inductive capacity of the paraffined paper may be taken at 2·8. Calculations made from a condenser constructed of "tinfoil paper" would give results somewhat higher than this figure, due to the fact that the effective thickness of the body paper is less than its apparent thickness owing to the particles of tin being so

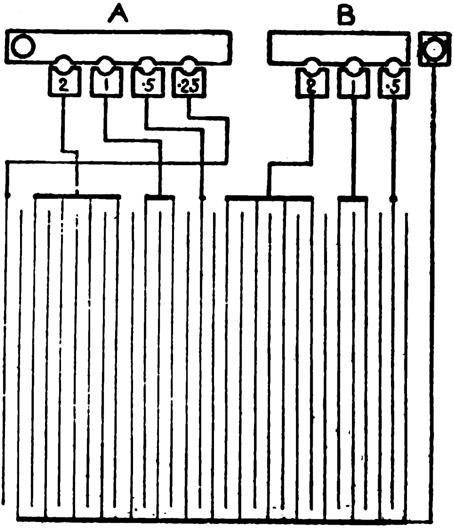

FIG. 122.—Arrangement and principle of 7½ m.f. condenser.

thoroughly driven into the pores of the paper in the process of manufacture. The insulation resistance obtained from a condenser depends upon many details of manufacture, and also upon the conditions under which the test is made, particularly as regards temperature. It is useless to look for high insulation unless the last traces of moisture have been removed from the paper, and unless the paraffin wax and the paper are of the highest quality.

It should be added that the whole arrangement is firmly clamped between iron plates in precisely the manner described in the case of the older type of condenser.

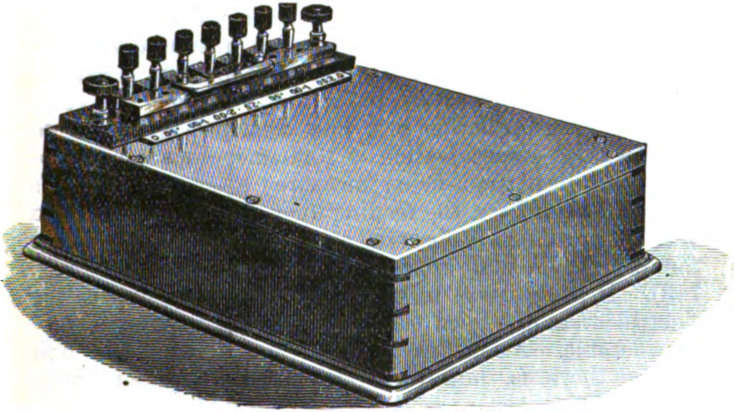

Fig. 123.—7½ m.f. condenser.

The external appearance of the 7½ m.f. condenser and its connections are shown in Figs. 122 and 123. It is divided into two sections in order that it may be used in place of the two separate condensers which would otherwise be required upon long duplex and other circuits. The seven section lugs are connected to condenser plates of the capacities indicated in Fig. 122. Capacity is inserted by plugging the main and section bars together. To obtain the full capacity 7½ m.f. *A* and *B* are joined together and all the plugs inserted so as to connect all the plates of the condenser together.

INSULATION OF CONDENSERS.

Immediately the insulation of a condenser fails it becomes a mere resistance and incapable of holding a charge.

For use upon cable circuits condensers of far larger capacity and divided into three sections are frequently employed. This point is however dealt with in connection with duplex circuits.

SPECIFICATION OF INSULATION AND CAPACITY.

The temperature coefficient of the insulating materials being very high, a standard temperature must necessarily be decided upon, and this in the case of condensers is usually 60° F. At this temperature, and with a pressure of 400 volts, the minimum insulation of a new condenser according to the Post Office specification is 1000 megohms per microfarad, the insulation being measured after one minute's "electrification," *i. e.* the reading upon which the insulation is to be calculated is observed at precisely one minute after the battery is first applied to the conductor (see page 743). It is necessary to be precise upon this point as the electrification of a good paraffined paper condenser is very considerable. As compared with that during the first minute there is, however, very little subsequent electrification.

The insulation of a 7¼ m.f. condenser after one minute's electrification would, at 60° F., have to be at least 138 megohms.

The capacity of telegraph condensers is correct to 5% above or below their nominal values.

CONDENSER DISCHARGE.

The discharge of a condenser when employed in ordinary telegraphy is always accomplished by a flow of current from the positive to the negative side of the condenser through the circuit connecting them. If, however, the resistance and inductance of the discharging circuit are extremely low and bear a certain relation* to the capacity of the condenser, the discharge becomes oscillatory. This phenomenon plays a vitally important part in wireless telegraphy, and it may best be explained by analogy. Take a flat piece of whalebone 3 or 4 inches in length and clamp one end in a suitable hand-vice. If the whalebone is deflected and suddenly released it will vibrate backwards and forwards past its normal position of rest, but the amplitude of its vibration will grow gradually less and less until finally all vibration ceases. This experiment is supposed to have been made in air, and it is the friction between the moving whalebone and the air which finally brought it to rest. Let the same experiment be repeated, but with the whole arrangement immersed in treacle. When the spring is pulled aside and released it will slowly return to its normal position without oscillation, because the frictional resistance is too great. In this analogy the spring corresponds to the charge of the condenser, and the medium in which it dissipated its energy to the external circuit through which the condenser is discharged. If the resistance and inductance of the circuit is small, the charge swings backwards and forwards, first from the positive to the negative side, and in overshooting its mark makes the formerly negative side positive, and the formerly positive side negative. This results in a discharge in the reverse direction, which again overshoots the mark, and makes the formerly positive side again positive. This oscillatory current continuously diminishes in magnitude until, finally, it dies away altogether.

THE DOUBLE CURRENT SYSTEM.

In the single current system the tongue of the relay is restored to the normal position upon cessation of the current either by a magnetic bias, or by a spring in the cases where non-polarized relays are employed. In the double current system a polarized relay is necessarily always employed, and a current in the reverse direction to the marking current is employed to restore the tongue to the spacing side. This current is termed the "spacing" in contradistinction to the "marking" current, *i. e.* the current which causes the completion of the local circuit. The difference between a series of signals sent under the two systems is that in the double current arrangement the blank spaces between the "marking" currents of the single current system are filled by a reverse or spacing current. At rest the key sends out a spacing, and when depressed a marking current, which latter is in the same direction as that in the single current system.

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* The discharge is oscillatory if the ohmic resistance of the discharging circuit is less than the square root of four times the inductance in henrys divided by the capacity of the condenser in farads.

ADVANTAGES OF DOUBLE CURRENT SYSTEM.

The use of the double current system upon long lines increases the speed of working, and gives greater permanence of adjustment as compared with single current working. The causes of these advantages may be summarized as follows:—

1. It hastens the discharge of the line which is ordinarily comparatively slow.
2. The relay is worked in the neutral, and therefore in its most sensitive and rapid condition.
3. It eliminates the effects of residual magnetism in the cores of the receiving relay.
4. The effects of a variation of received current are reduced since both marking and spacing currents are equally affected, and the instrument is therefore self-adjusting.

REVERSE CURRENT AND CHARGE UPON THE LINE.

In order clearly to realize the effect of the spacing current it is necessary to consider the effect of the capacity of the line upon the working of a circuit.

A condenser has been defined as two conductors separated by an insulating medium, and it will therefore be seen that any telegraph line may be regarded as a condenser. The aërial line wire itself forms one conductor, and the earth below it the other. These two conductors are separated by air, and there are, therefore, all the essential features of a condenser. In the case of a subterranean or submarine cable the wire and the earth are much closer together, and the gutta-percha insulation which separates them has a much higher specific capacity than air. The result is that the capacity of an underground circuit is far higher than that of an open line. In fact, one mile of gutta-percha underground has approximately the same capacity as twenty miles of open line. With the almost universal use of air-space cable this disadvantage has, however, been materially reduced.

When an earthed battery is connected to a telegraph circuit the capacity of the line has to be satisfied before the full value of the current is received at the distant end. The charging of the line as a condenser occupies a definite length of time which is much greater for very long or underground circuits than for short open lines. This phenomenon, viz. the delay in the appearance of current at the receiving end after the connection of the sending battery, is termed retardation. Upon stopping the current the line discharges the quantity of electricity upon it. This discharge current flows from the line at both ends if both are earthed, and at the receiving end it tends to prolong the mark. This is termed prolongation. The discharge is also comparatively slow, and therefore on very long circuits the interval between successive signals must be made greater in order that the signals may not run together. Very sharp dots would be lost entirely, due to the quantity of electricity sent on to the line being small and insufficient to charge it fully. The small quantity of electricity would distribute itself over the line and a very small discharge current would probably flow out at both ends. That at the receiving end would be quite insufficient to actuate the apparatus.

When the double current system is employed the reverse current hastens the discharge of the line which occurs almost entirely through the sending battery. At the moment when the sending battery is reversed, to the E.M.F. of the charge on the line is added the reversed E.M.F. of the battery; hence the E.M.F. tending to reverse the charge is twice that of the battery employed.

In single current working each individual mark is shortened in the following way. Assume that, on a single current circuit working with 20 m.a., the tongue moves over to *M* when the current through the relay has risen to 10 m.a. After depression of the key the mark does not commence until the current has risen from zero to 10 m.a. On the release of the key the mark ends immediately the current falls to 10 m.a. This time is very short as compared with the time taken for the current to rise to 10 m.a., and the received signal is therefore much shorter than that formed on the sending-key. Consideration will show that a double current signal received on a neutrally adjusted relay is not clipped. In the first place the mark would commence earlier (at, say, 3 m.a.) due to the absence of bias, and would not end until the current had risen to an equal value (3 m.a.) in the reverse direction.

DETAILED EXPLANATION INVOLVING KNOWLEDGE OF CHAPTER VIII.

The precise behaviour of the reverse current may readily be deduced from a consideration of the principles explained upon page 267 *et seq.* The charge upon a line due to a marking current from an up station is represented by a triangle similar to that shown in Fig. 142, but drawn above the line as in Fig. 200. If, now, the sending end is suddenly earthed, as by releasing a single current key, the line discharges, two-thirds of the charge flowing to earth at the sending and one-third at the receiving end. This one-third is in the same direction as the marking current, and therefore prolongs the signal. Had the battery at the sending end been reversed instead of earthing the line it will be seen that practically the whole of the discharge of the line would pass through the reversed battery. This would clearly prevent the prolongation of the signal.

Consider now the case where the line is negatively charged by the spacing current as shown in Fig. 142. Instantly the battery is reversed a heavy current flows from it, reversing the sign of the charge upon the line and reproducing the conditions described above. But during this process, rapid as it is, a certain portion of the previous negative charge is dissipated by a negative discharge to earth at the receiving end. This expedites the process of clearing the negative charge before the reverse charge is commenced. The discharge at the receiving end is in the spacing direction, and therefore the actual marks are unaffected.

OTHER ADVANTAGES OF THE DOUBLE CURRENT SYSTEM.

The reverse current reverses the magnetization of the relay, and therefore the effects of residual magnetism are minimized (see page 176).

The advantage stated under the heading 3 on page 240 also carries with it the corollary that less battery power should be required to work double instead of single current, because there is in the former case no magnetic bias to be overcome. In practice, however, a small spacing bias is always given to the relay in order to prevent the sounder from chattering. For, if the relay is set exactly neutral, it is so sensitive that the extremely minute currents induced by neighbouring working circuits or by slight earth or stray currents will cause the tongue to vibrate. Upon the other hand, if the tongue continuously remains at *M* when the circuit is idle the local battery is needlessly used.

The last advantage, stated under heading 4, is one of considerable practical importance. Since the marking and spacing currents will be equally and similarly affected by a variation in the received current, the instrument is consequently self-adjusting. In the case of a single current set the relay is given a definite and constant bias, and variations in the value of the current received therefore produce irregularity in the received signals. Again, where a number of stations are placed upon one circuit the current sent out by each office varies, and, with the single current system, working becomes practically impossible on account of the re-regulation of the relay which is required for each station. Part of this trouble is of course due to residual magnetism. With double current working there is practically no bias upon the relay, and re-regulation is obviated since an office from which a weak marking current is received also furnishes an equally weak spacing current. The office sending a strong marking current also sends an equally strong spacing current, and the working of the relay is therefore not affected by the difference. With the single current system a large current would leave a considerable amount of residual magnetism.

DOUBLE CURRENT KEY.

The double current key (Fig. 127) is provided with a switch, which joins up the relay for reception in one position, and in the other connects the battery between the up and down terminals in a direction which depends upon the position of the key. It will be obvious that,

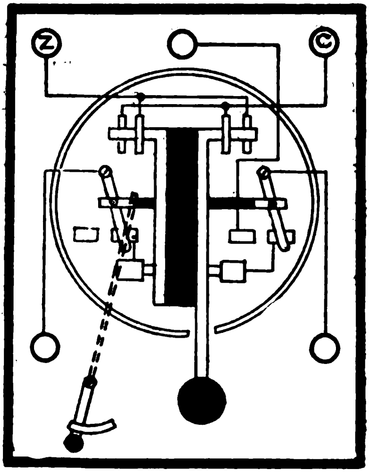

FIG. 124.—Plan of a double current key.

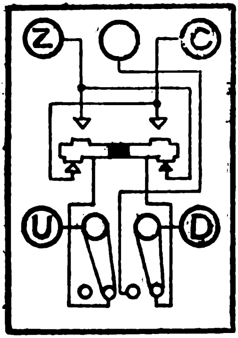

FIG. 125.—Conventional diagram of a double current key.

since the key when at rest sends out a spacing current, a means of disconnecting the battery and joining up the receiving apparatus must be provided. This is, then, the function of the "send" and "receive" switch fixed upon the left side of the key-handle.

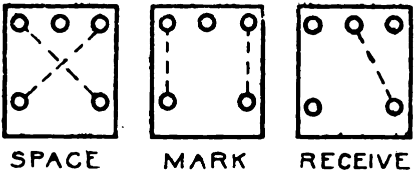

Fig. 126.—Skeleton connections in each position of the key.

The key is furnished with five terminals, two of which, *Z* and *C*, are used for the battery, two for the up and down sides of the key, and one, the centre terminal, for the receiving circuit. The key itself consists of a divided lever furnished with four contact points which play between four platinum-tipped springs connected to *Z* and *C*. A section of the end of the key with the lever in its lower position is shown in Fig. 125.

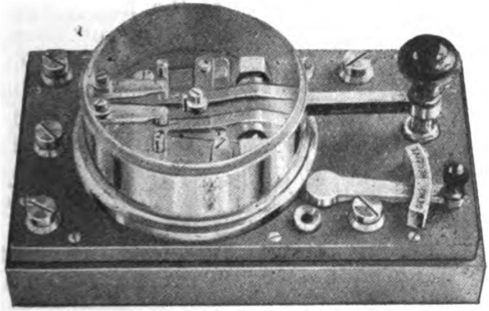

Fig. 127.—Double current key.

Terminal *C* is thus connected through the lower "copper" spring and left-hand side of the lever through the right-hand side of the left switch lever to *U*. *Z* is connected via the lower "zinc" spring and right side of the lever through the right contact of the right switch to *D*. Upon depression of the key the end rises and the left side of the lever breaks contact with the lower "copper" spring and makes with the upper "zinc" spring. The right side of the lever, simultaneously, breaks with the "zinc" and makes with the "copper" spring, the result being that *Z* and *C* are respectively connected to *U* and *D*. Upon the handle of the switch being moved to "receive," the two levers of the switch, which are mechanically (but not electrically) joined together, move over to their left contacts, thus disconnecting the key lever altogether, and joining the centre terminal to *D*. In the latest form of key the four contacts on the divided lever are adjustable contact screws. The skeleton connections in each position of the key are shown in Fig. 126.

CONNECTIONS OF DOUBLE CURRENT SOUNDER.

The galvanometer employed is of the single current pattern previously described (page 186).

The connections of a double current set are shown in Fig. 128. *Z* and *C* are connected to the battery, the front right-hand terminal of the key is connected to the left of the galvanometer whose right terminal forms the down line terminal of the set. The left side of the key is connected to *U*-circle of the relay which forms the up line terminal of the set. The centre terminal of the key is connected to *D* of the relay. It may be noted that the connections of the single current sounder are similar in several respects to those now under consideration. The front right terminal corresponds to the middle point of the single current key and the centre to

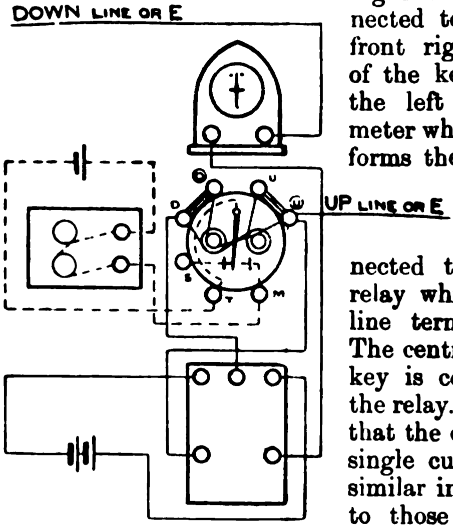

FIG.—128. Double current sounder connections.

the back stop. The up and down line terminals of the set are also the same.

When the key is depressed the direction of the current is the same as in the single current set, and with the exception of the difference in the keys, its path also is identical.

The connection of the set to line and earth or between up and down lines at a terminal office is the same as that of the other instruments previously considered.

PATH OF CURRENT.

The path of the current with the switch to "send" but key at rest at the up station is as follows. From the positive pole of the battery, to *C*, to the left terminal of the key, to *U*-circle, to earth through the down galvanometer from right to left, to the right side of the key, to the centre of the key, to *D* of relay, through the relay in the direction *D* to *U*, to line, through the up galvanometer from right to left, to the front terminal of the key, to *Z* and thence back to the negative pole of the battery. The tongue of the relay at the down station is therefore held over to *S*. Upon depressing the key the current is reversed and the tongue moves over to *M*, thus completing the local circuit and registering a mark at the down station.

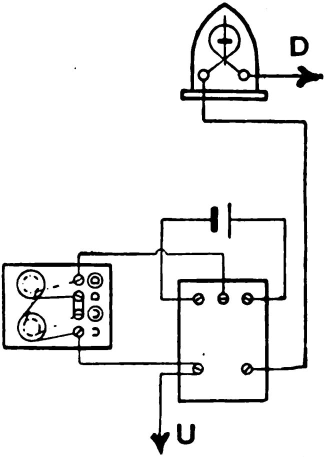

Fig. 129.—Double current working with polarized sounders.

The correctness of the apparatus connections may be verified by joining the centre of the key and the wire upon it to the right-hand terminal of the galvanometer and working the key, when the signals sent upon it will be received reversed. It should, however, be noted that the connection made by the switch from the right side of the key to the centre is not included in the test.

USE OF DOUBLE CURRENT SET FOR SINGLE CURRENT WORKING.

It is occasionally required temporarily to convert a double current into a single current set. This may be done as follows. Take the wire from the front left terminal of the key and join it to the *Z* wire, leaving both terminals free. *Z* and the centre terminal should be connected by a short length of wire and the switch of the key placed at send. *Z* and the centre terminal now correspond to the back stop of the single current key.

"D C" DIRECT WORKING WITH POLARIZED SOUNDER.

The relay, sounder and local battery in Fig. 128 may be replaced by a $500^{\omega} + 500^{\omega}$ polarized sounder for direct working (Fig. 129). This arrangement is quite satisfactory for practically any circuit within the United Kingdom. The range of the instrument when properly adjusted is from 3 m.a. to 40 m.a., *i. e.* the current may be as low as 3 m.a. or as great as 40 m.a.

BATTERY POWER AND CURRENT REQUIRED.

Leclanché No 1. cells are employed for the line battery, a sufficient number of cells to furnish a current of from 14 to 17 m a. being required. The local battery is a 3-cell No. 1. It is obvious that a local inker may be substituted for or added to the sounder in the manner previously described.

With the polarized sounder 10 m.a. will suffice.

It should perhaps be added that the only case in which the coils of the relay should be joined in parallel is when there are several stations upon a very short line—the deciding factor being economy of battery power.

CHAPTER VIII

THE DIFFERENTIAL DUPLEX.

THE SINGLE CURRENT DUPLEX.

SYSTEMS OF DUPLEX WORKING.

DUPLEX working consists in the simultaneous transmission of two messages in opposite directions over a single wire connecting the two stations. There are many methods of doing this, those in practical use being the Bridge method (Chapter XI), the various Central battery duplex methods (Chapter XVI), and the differential method. The differential duplex is the method most largely employed, and it is worked upon either the single or the double current system. In the former system the working may be arranged in two different ways which may be distinguished as "opposition" and "combination" methods respectively. The latter is employed by the Post Office, but a consideration of the former also is desirable.

In order to realize clearly the underlying principles in duplex working it will be well to ascertain why the ordinary single current sounder will only permit simplex working. Consider two stations *A* and *B* sending the signals depicted in Fig. 130. These signals and spaces are divided into fifteen parts by the vertical lines so as to show the cases in which two marks are simultaneously sent out.

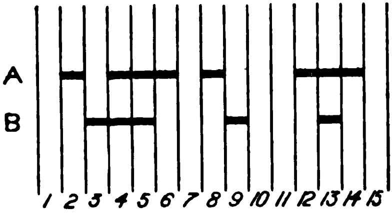

FIG. 130.—Signals.

In the first place both keys are at rest, whilst in the second *A* depresses the key and so produces a dot at *B*. As this key rises *B* depresses his key and the result is a mark at *A*. Whilst this mark is proceeding, *A* depresses his key (4) so cutting out his sounder and stopping the mark which he should be receiving. *B*'s sounder also is cut out by the depression of his key, and therefore no marks are recorded at either end when both keys are down. When only one key is down at a time the signals are of course transmitted without difficulty, but when both keys happen to be simultaneously depressed (4, 5 and 13) confusion at once results.

In the opposition method of duplex working, when only one key is depressed, the marks are made by the current which is received from the distant station, just as in ordinary simplex working. When, however, both keys are simultaneously depressed, a special condition is established which causes both sounders to register a mark.

OPPOSITION METHOD.

The general principle of the opposition method consists in splitting the current sent out by the key into two exactly equal parts which respectively pass through the two coils of the sending station's relay. The two currents are of precisely equal strength and pass through the two coils of the relay in opposite directions, so producing no effect upon the sending station's relay. One-half of the current passes to line and through the receiving relay, thus effecting a mark. When both keys are depressed, the two batteries have their similar poles to line. This stops the line current, but leaves the current flowing in the other coil of the relay free to produce a mark. When one key only is depressed the mark is made by the current received from the sending station, but when both keys are down each relay marks with the current from its own battery, due to the stoppage of the line currents.

The skeleton connections of such a circuit, worked with standard relays, are depicted in Fig. 131, but it should be noted that the local circuit has been omitted in order to simplify the diagram. The single current key when at rest earths the split of the relay, and when depressed joins up the earthed battery. One coil of the relay is connected to line and the other to a resistance equal in value to the resistance of the line and the distant apparatus. This resistance is adjusted until the current sent out divides equally between the plain and circle coils of the relay. The arrangements at each end are identical in every particular.

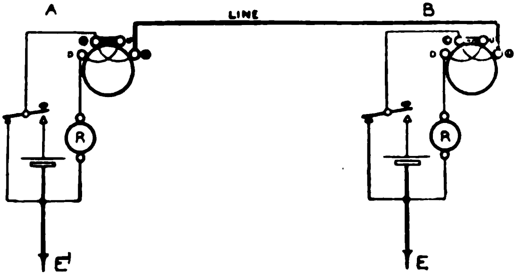

FIG. 131.—Opposition method of duplex working.

OPPOSITION METHOD, PATH OF CURRENT.

The paths of the current may best be considered by tracing the conditions which result when *A* and *B* send the signals shown in Fig. 130.

Condition 1.—Both keys at rest. Tongue held to *S* by magnetic spacing bias given to the relays. No currents flowing.

Condition 2.—*A*'s key depressed. Current flows from the positive pole of *A*'s battery to the split of the relay. Line half of the current passes through the *D* circle *U*-circle coil of *A*'s relay, along the line, through the line coil of *B*'s relay from *U*-circle to *D*-circle (thus producing a mark), to the centre of *B*'s key, to earth, and thus back to *A*'s battery. The other half of *A*'s current passes through the plain coil of the relay in the direction *U* to *D*, rheostat *R*, and so back to the negative pole of the battery. This circuit is termed the "compensation" circuit in contradistinction to the "line" circuit. Since the currents in the line and compensation circuits are equal but in opposite directions the relay is not magnetized and no effect is produced at *A*. *B*'s relay, however, marks by the current received from *A*.

Condition 3.—*B*'s key only is depressed. The current from *B*'s battery divides equally between the line and compensation circuits, and as the two halves pass in opposite directions through the two coils of his relay no effect is produced upon it. *A*'s relay marks with the half of the current which is received from *B*.

Condition 4.—Both keys simultaneously depressed. Both batteries have their negative poles to earth and their positives to line. Since they are of approximately equal E.M.F. no current can flow along the line or line coils of the relays. The only path left open to the current is, at *A*, from the positive pole of the battery, through his own relay from *U* to *D* through the rheostat back to the negative pole of his own battery. Since there is no opposing effect from the circle coil a mark is made at *A* by his own battery. Similarly *B*'s relay marks by the current from his own battery through *U D* coil of his relay. Both relays therefore mark.

Condition 5.—Same as condition 4.

Condition 6.—*B*'s key released, *A*'s still down. When *B* releases his key, *B*'s battery is cut out and *A*'s line current is therefore unopposed. The moment this is re-established *A*'s compensation effect is balanced and his relay spaces thus ending the mark at *A*. At *B* the mark is continued by the current received from *A*. The state of affairs is identical with that of condition 2.

Conditions 7, 10, 11, 15.—Same as condition 1.

Conditions 8, 12, 14.—Same as condition 2.

Condition 9.—Same as condition 3.

Condition 13.—Same as conditions 4 and 5.

INTERMEDIATE POSITIONS OF KEYS.

There still remains, however, one other point which must be considered. Take, for instance, conditions 3 and 4. It will be seen that, at the beginning of 4, *B*'s key is already down whilst *A*'s key is being depressed, and that there is therefore an instant of time in which *A*'s key is touching neither the front nor the back stop of his key. In this case the line current sent out by *B* passes along the line, through both coils of *A*'s relay in series, and through the rheostat to earth. The received current is therefore only half as great, because it has encountered twice the resistance. Since, however, it has passed through both coils of *A*'s relay the strength of the mark is unaffected. At *B* the line and compensation currents do not balance, as they are of unequal strength. The compensation current therefore tends to mark until *A*'s key touches the front stop.

USE OF NON-POLARIZED RELAYS AND DIRECT WORKING.

In the exposition of this method standard relays have been depicted, but a little consideration will show that non-polarized relays or either a differentially wound polarized or ordinary non-polarized sounder or inker for direct working might equally well have been employed.

DIFFERENTIAL GALVANOMETER.

Before the combination or P.O. differential duplex is considered it will be advisable to describe the differential galvanometer, Fig. 132, employed in conjunction therewith. The two coils have each a resistance of 50ω and each is shunted by a 300ω resistance coil, the purpose of which (to reduce the inductance) is considered in Chapter X (Wheatstone). The effect of the shunt is to reduce the combined resistance of each coil to 42·9ω. The magnetic needle is induced, and is either of the Varley or Spagnoletti type, and differs but little from the single needle dials previously described (page 195). In the older or Varley form the two-bar magnets were placed upon the lower sides of the coils instead of above them in order to economize the size of the case.

Upon each side of zero the scale is divided into degrees, and up to 30° the current is approximately proportional to the deflections produced. Using one coil only, or both in parallel, the value of one degree is $\frac{2}{5}$ m.a., which gives 20° = 8 m.a. and 30° = 12 m.a. (actually, 11 m.a.). Beyond this point the current required to produce a given deflection is much larger than $\frac{2}{5}$ m.a. per degree. For instance, 50° corresponds to 25 m.a. and 60° to 40 m.a. When the deflections are produced by the coils in series the currents are, of course, one-half the values given above.

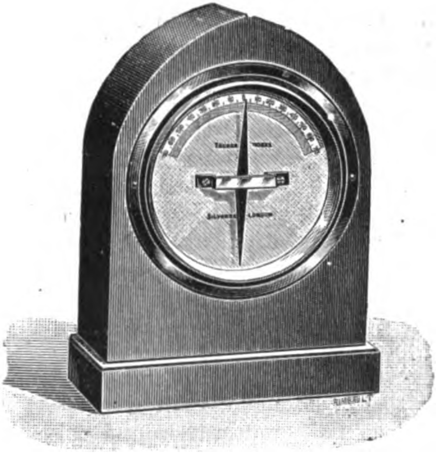

FIG. 132.—Differential galvanometer.

The specified figure of merit of the instrument is 20 m.a., with which current, flowing through both coils in series, a deflection of from 40° to 45° should be obtained.

P.O. OR COMBINATION METHOD OF DUPLEX WORKING.

In the opposition method of duplex working the compensation circuit tended to mark and the line circuit to space. When the line path was stopped by the two batteries opposing each other the compensation circuits marked. The P.O. or combination method differs from this in the fact that when both keys are depressed the two batteries combine together in the line circuit. There is therefore twice as large a current in the line circuit as in the compensation circuit. The line coil of the relay tends to mark, and the signal is produced by the preponderance of the line current's effect over that of the compensation circuit at either end.

The internal apparatus connections are identical at the two ends of the circuit, and the combination of the batteries is effected by reversing line and earth. In fact, just as in the case of every form of apparatus described, there is an up and a down line terminal whose connections to line and earth are determined by whether the office is an "up" or "down" station.

The single current key is connected between the strapped terminals of the relay and the lower terminals of the galvanometer (Fig. 133). The small resistance coil *r* is equal in value to the internal resistance of the battery, and the resistance of the circuit is therefore the same in either position of the key. The method of joining up the key between the galvanometer and relay is often termed the "double split," a most unfortunate designation and one which frequently produces confusion in the minds of students. If a current divides between two paths it is evident that the two parts must re-unite at some point. In this case the current splits at the lower terminals of the galvanometer and re-unites at the strapped terminals of the relay. The original object of the arrangement was to simplify the type of single and duplex switch. The rheostat contains resistance equal to that of the line and distant receiving apparatus, the latter comprising the right coil of the galvanometer, resistance block *r*,* and the circle coil of the relay.

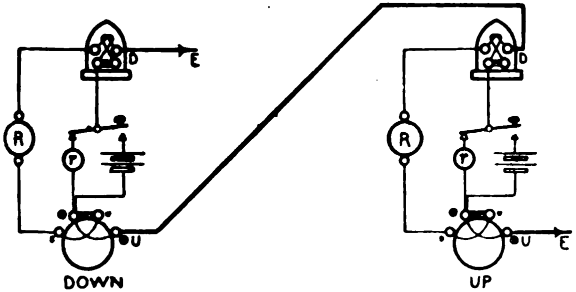

FIG. 133.—Skeleton connections of single current duplex.

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* To be strictly accurate, account must be taken of the fact that "*r*" is shunted by the compensation circuit, and that the combined resistance of both is slightly less than "*r*." For all practical purposes this may, however, be ignored.

PATH OF CURRENT.

After the detailed description of the conditions of duplex working given in the case of the opposition method it will, in the present instance, be unnecessary to do more than indicate the path of the current in each position of the keys.

When the down station depresses his key the current flows from the positive pole of the battery to the galvanometer, where it divides equally, the line half going to earth, in at the up station's earth, through his relay *U*-circle to *D*-circle (producing a mark), through *r*, back stop of the key, through the right or line coil of the galvanometer, along the line, through the *U*-circle *D* circle coil of the down relay (*tending* to mark) back to the negative pole of the battery. The other half of the down station's current passes through the left or compensation coil of the galvanometer, through the rheostat and *D U* coil of the relay (*tending* to space) back to the negative pole of the battery. At the down station no effect is produced upon the apparatus because the line and compensation currents are equal in value but opposed in effect. The mark and galvanometer deflection at the up station are due to the current received from the down station. At the down station the current splits at the galvanometer and the two parts re-unite at the strapped terminals of the relay. It should also be noted that although the current passes directly to earth at the down station, it has to traverse the resistance of the line and distant receiving apparatus before it can return to the down battery.

Upon depression of the up station's key, his current splits equally between the line and compensation circuits, and therefore produces no effect upon his own apparatus. The line half of the current passes along the line to the down station, through the *U*-circle *D*-circle coil of the relay (producing a mark), *r*, and line coil of the galvanometer to earth and thence back to the battery. As before, the mark is made by the current received, as in simplex working.

When both keys are depressed the batteries combine together in the line circuit, thus producing a current of twice the strength of that in each compensation circuit. The path of the line current is from the positive pole of the down station's battery through the line coil of the galvanometer, to earth, through the up station's *U*-circle *D*-circle coil of the relay, through the up station's battery (acting in the same direction), through the line coil of the galvanometer, along the line, through the down station's *U*-circle *D*-circle coil of the relay back to the negative pole of the battery. The direction of this current is from *U* to *D* in both relays, and a mark is produced upon both. The path of the current in each compensation circuit is the same as before, but the current is in each case due to its own battery only and is therefore of the same strength. The line current, being due to the two batteries acting in series, is of twice the value, and the resultant effect is therefore equivalent to the current received when only one key is depressed.

NUMERICAL VALUES OF CURRENT IN EACH PART OF THE CIRCUIT.

The case will perhaps best be illustrated by a numerical example. In order to simplify the calculation the internal resistance of the battery and *r* will be taken as negligible. Let the resistance of each coil of the galvanometer be taken as 43^{ω}, that of the line as 264^{ω}, and each coil of the relay as 200^{ω}—

Resistance in each rheostat $= 264 + 43 + 200 = 507^{\omega}$

Total resistance of line circuit $= 200 + 264 + 43 + 200 + 43 = 750^{\omega}$.

Total resistance of each compensation circuit $= 750^{\omega}$.

Let the E.M.F. of each battery $= 7\cdot5$.

$$\left.\begin{array}{l}\text{Current in line circuit (both keys}\\ \quad\text{depressed) ... ...}\end{array}\right\}=\frac{7\cdot5+7\cdot5}{750}=20\text{ m.a.}$$

$$\left.\begin{array}{l}\text{Current in each compensation}\\ \quad\text{circuit ... ...}\end{array}\right\}=\frac{7\cdot5}{750}=01\text{ m.a.}$$

Current in line circuit (one key depressed) ... . $= \frac{7.5}{750} = 10$ m.a.

Current in compensation circuit at sending end (one key depressed) ... ... $= \frac{7.5}{750} = 10$ m.a

The received current when one key only is depressed is 10 m.a., and this passes through one coil of the receiving relay. When both keys are down the line coils of the relays carry 20 m.a. and each compensation circuit 10 m.a. The net effect upon the tongue of the receiving relay is precisely the same as that produced when the distant or sending station's key only is depressed.

INTERMEDIATE POSITIONS OF KEYS.

The last condition which remains to be considered is the path of the current when one key is depressed and the other momentarily occupies a mid-way position. In this case the path of the current at the receiving end is through both coils of the galvanometer, through the rheostat and both coils of the relay. Taking the above figures, the value of the current is 5 m.a., but as this passes through both coils of the relay its effect is the same as 10 m.a. upon one coil. At the sending end the current in the compensation circuit is as before 10 m.a. upon one coil tending to space, opposed by 5 m.a. upon one coil tending to mark. It will be therefore noticed that, whilst the combination method tends to end the mark instantly contact is broken with the front stop of the key, the opposition method tends to prolong it until contact is made with the back stop.

SKELETON CONNECTIONS REQUIRED FOR SIMPLE DUPLEX.

The connections depicted in Fig. 133 are the actual connections which are formed when the duplex and single switch is turned to the duplex position. It is, however, desirable to be able to revert to simplex working at will, since it occasionally happens that line faults which will prohibit duplex will not stop simplex working. In order to convert the connections of Fig. 133 into those of the single current sounder (Fig. 119) the negative pole of the battery must be disconnected from the relay split and joined to *U*-circle. *D* of the relay must be taken off the rheostat and joined to the back stop of the key. These alterations are shown in Fig. 134, and it will be seen that they can readily be made by means of two two-way switches. The resistance coil *r* remains in circuit, and unfortunately acts as a shunt on the *U D* coil of the relay. Its effect is not of a very serious character, but for universal working (Chapter XVIII), a 9-terminal-2-position switch is used to disconnect it during simplex working.

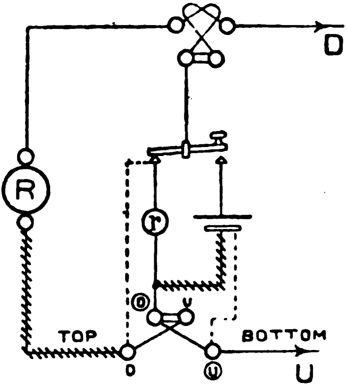

FIG. 134.—Alterations to single current duplex connections required for simplex working. The scored connections are required for duplex and the dotted connections for simple working. "Top" and "bottom" refer to arrangement of the duplex switch.

DUPLEX SWITCH.

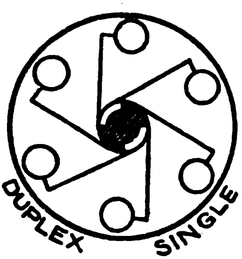

FIG. 135.—Duplex switch arrangement of springs and contact pieces.

The duplex switch (officially termed a 6-terminal 2-position switch) is essentially two two-way switches controlled by one lever. The six terminals are equally spaced round the wooden base of the instrument beneath which they are respectively joined to six brass springs. The springs rest upon a round piece of ebonite carrying two insulated segments of brass. In the position shown (Fig. 135), the bottom terminal and its left-hand neighbour are connected, whilst the top terminal and that to the right are also connected. When the handle is moved to the right, or simplex, position the central portion moves with it, so connecting the springs then lying upon the two brass segments. The terminals between which the handle lies are connected, as well as those opposite (*vide* Figs. 136 and 137).

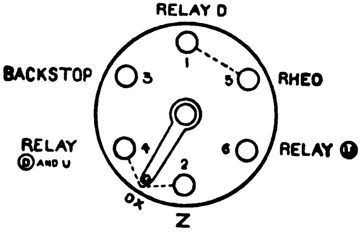

FIG. 136.—Duplex switch connections when the lever is turned to "duplex."

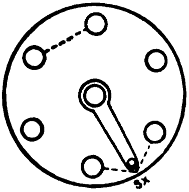

FIG. 137.—Duplex switch connections when the lever is turned to "single."

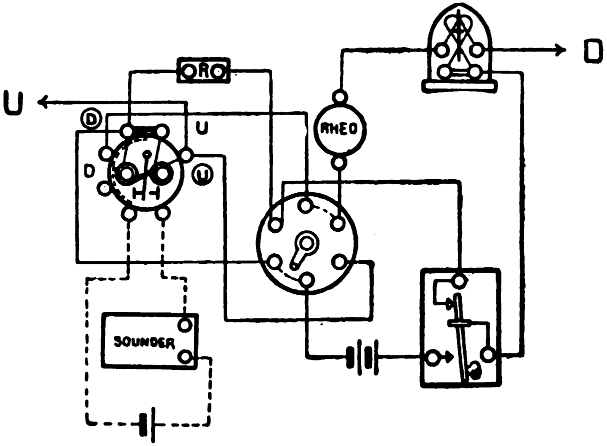

FIG. 138.—Connections of single current duplex.

In a later form of switch the terminals are connected to six segmental pieces of brass arranged round the underside of the switch and two insulated U-shaped pieces of brass, both mechanically connected to the switch lever, form the connections. The result is the same as in the older switch, but the arrangement is considerably simpler and cheaper (see Fig. 161).

CONNECTIONS OF DUPLEX SWITCH.

The connections made and broken by the duplex switch are clearly indicated by Fig. 134, and can be compared with Fig. 136. The full connections of the set are shown in Fig. 138.

BALANCING.

If the home key only is depressed the tendency of the current in the line circuit is to mark and that in the compensation circuit to space. The direction in which the galvanometer needle deflects therefore indicates which of the circuits is carrying the larger current, and, consequently, whether the resistance in the rheostat is too high or too low. The principle to be adopted is to balance as nearly as possible with the 400^ω arm, and then, leaving this arm at the lower value, to deal similarly with the 40^ω, and, if necessary, use the 10^ω and 20^ω coils to obtain the accurate balance. The matter is, however, more fully dealt with in connection with the double-current duplex (see page 281).

USEFUL FACTS.

The full connections will be readily memorized by the aid of Fig. 134, but the following points will doubtless assist :—

1. Right side of galvanometer is the down line terminal of the set.
2. *U*-circle of the relay is the up line terminal of the set.
3. Positive pole of the battery is connected to the front stop of the key.
4. Line coil of the relay tends to mark and compensation to space.
5. Up station puts positive to line to mark.

The last two statements are chiefly valuable in checking the correctness of connections.

DIRECT WORKING WITH POLARIZED SOUNDER.

The relay, sounder, and local battery in Fig. 138 may be replaced by a polarized sounder.

DIFFICULTY IN WORKING VERY SHORT CIRCUITS.

It is not possible to work a duplex circuit through a line of very low resistance without special arrangements. For instance, it is impossible for satisfactory working to be obtained between two sets in the same office or over a circuit which is only one or two miles in length. The reason is that, in the ordinary arrangement, no account is taken of the inductance of the distant receiving apparatus. In the compensation circuit there is one coil of the relay, one of the galvanometer and a resistance equal to that of the line and one coil of the relay and one of the galvanometer at the distant end. In the line circuit there are, therefore, one coil of the home galvanometer, one of the home relay, the line itself, and one coil each of the distant relay and galvanometer. Whilst the compensation is equal in resistance to that of the line circuit, the inductance of the line circuit exceeds that of the compensation circuit by an amount equal to the inductance of one coil each of the galvanometer and relay. In the majority of cases this lack of balance has no practical effect, but upon very short circuits it renders duplex working quite impossible owing to the false signals produced by working the key. In fact, the effect is similar but opposite in direction to the "kicks" due to unequal capacity in the line and compensation circuits dealt with in a subsequent section of the present chapter.

One solution of the difficulty is artificially to increase the resistance of the circuit to such a value that the E.M.F. of self-induction produces only a negligible current. This may entail the use of extra battery power, and the better plan is therefore to include in the compensation circuit a coil having an inductance equal to that of one coil of the relay and the coil of the galvanometer.

These remarks apply equally to double current duplex and to quadruplex working.

BATTERY POWER AND CURRENT REQUIRED.

The line battery is of Leclanché No. 1 cells, and a current of from 15 m.a. to 20 m.a. is required. The local battery is either a 3-cell No. 1.

Although single current duplex working may be employed upon any circuit under 25 miles in length, there are very many circuits of far shorter length which are worked double current.

THE DOUBLE CURRENT SOUNDER DUPLEX.

The advantages which have been claimed for the double current system in conjunction with simplex (page 240), apply with even greater force to duplex working. In fact, the number of single current duplex circuits in use at the present time is comparatively small, although there are very many cases where single current working could be quite satisfactorily employed.

CONDITIONS FOR DOUBLE CURRENT DUPLEX WORKING.

In the double current duplex a spacing current takes the place and performs the functions of the magnetic bias employed in single current working. Consideration will show that the following conditions must obtain :—

1. When both keys are at rest (switches to "send") the tongues of both relays must be held over to the spacing side.
2. When both keys are depressed (switches to "send") the tongues of both relays must be held over to the marking side.
3. When one key is at rest and the other depressed (switches to "send") the relay at the end where the key is depressed must space, and the other relay must mark.

SKELETON CONNECTIONS.

When both keys are depressed the skeleton connections and values of the currents in each portion of the apparatus are identical with those of the single current system when the keys at both ends are down.

The general connections for double current duplex working differ from those of the single current duplex merely in the substitution (between the strapped terminals of the relay and galvanometer) of a double current for a single current key. The rheostat is joined between the left side of the galvanometer and *D* of the relay, and contains resistance equal to that of the line and distant receiving apparatus. *U*-circle of the relay and the right-hand terminal of the galvanometer are respectively the up and down line terminals, and these are connected to line and earth in accordance with the principles already stated.

When both keys are at rest or both are depressed, the two stations' batteries combine together to produce an effect upon both stations' relays. The compensation circuits in both these cases carry a current of half the value of that in the line circuit, because the current in the latter case is produced by the two batteries in series, whilst in the former the current is due to each battery acting separately. The effect upon the relay is due to the preponderance of the current in the line over those in the compensation circuits. As this principle has already received ample consideration no further explanation should be necessary. It should also be apparent that when both keys are at rest the compensation circuit tends to mark and the line circuit to space.

When one key is depressed the battery at that end is reversed and consequently the direction of the current in its compensation circuit is changed. Instead of tending to mark it now tends to space, and, since the reversal of the battery causes the two stations' batteries to oppose each other, it is left free to produce this effect. At the distant end the compensation circuit marks.

Both keys at rest or both depressed.—The skeleton connections of a double current duplex circuit (both keys at rest) are depicted in Fig. 139. The path of the line current has been shown by dotted lines and arrows, whilst the compensation circuits are shown by full lines. The line current is twice as great as the compensation current, and, when both keys are at rest (as shown), passes through the circle coils of both relays in the direction *D* to *U*. If the current in each compensation circuit is 10 m.a. that in the line circuit is 20 m.a., whilst that in the battery from the galvanometer split to the relay split is 30 m.a., in each case. If both keys are depressed the direction of the current is everywhere reversed and both relays will therefore mark. The strengths of the currents in the various parts of the circuit are, of course, the same as in the previous case.

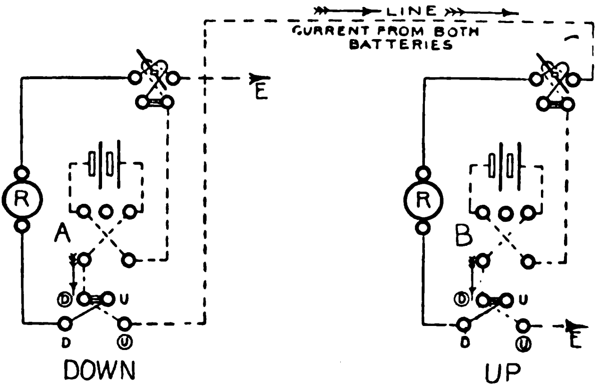

Fig. 139.—Skeleton connections of double current duplex. The path of the current due to both batteries is shown by dotted lines and the compensation current by the full lines.

One key only depressed.—The conditions which result when the down station depresses the key whilst the up station is at rest are shown in Fig. 140. In this case the two batteries have similar poles to line, and being of equal E.M.F., there is no current in the line circuit, therefore the compensation circuits are left unopposed. The paths and directions of the currents have, in each case, been indicated by dotted lines and arrows. The full lines in this figure represent parts of the circuit in which no current is flowing.

EFFECT OF CAPACITY OF LINE.

In order to render duplex working practicable, it is essential that the compensation circuit shall resemble the line circuit as closely as possible. A long or underground telegraph line possesses considerable capacity as well as resistance, and therefore a rheostat alone is insufficient for balancing. With short lines no provision need be made to balance the capacity, and a rheostat is therefore all that is required in the compensation circuit.

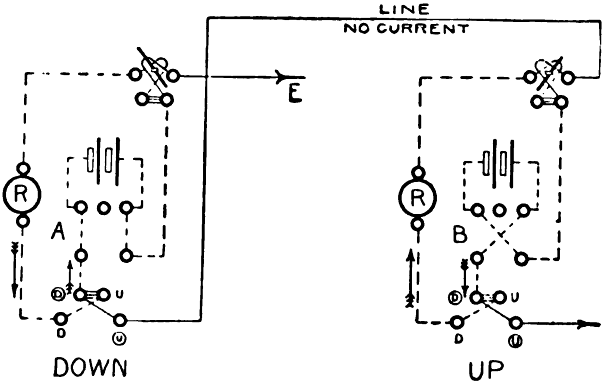

FIG. 140.—Skeleton connections of double current duplex. The path of the current in the compensation circuit is shown by dotted lines. The full lines indicate paths in which there is no current flowing.

It has been stated that a line has to be charged before any effect is produced upon the distant apparatus. Upon connecting an earthed battery to such a circuit there occurs a rush of current into the circuit to satisfy its capacity. If such a circuit were balanced only by a rheostat this rush of current into the circuit would momentarily upset the balance and so produce a "kick" upon the relay. During the time that the wire is being charged it behaves as though it offered little or no resistance to the charging battery. The resulting heavy rush of current into the line would preponderate over the steady current which would, almost instantly, commence through the compensation circuit—upon releasing the key the wire would discharge and a momentary upsetting of the balance would again result. It will be quite obvious that these irregularities of the sending current occurring in the middle of received marks would cause them to split and would be quite sufficient to preclude the possibility of duplex working upon long lines. It is therefore necessary to give to the compensation circuit an amount of capacity which will cause charges and discharges in that circuit equal in every respect to those of the line. This may frequently be accomplished by simply joining a condenser of the requisite capacity across the terminals of the rheostat. Later, it will be shown that this simple arrangement has to be considerably modified in the case of very long circuits. It will, however, amply suffice for the explanation of the paths and directions of the line and compensation circuit charge, discharge, and recharge, under working conditions. Before proceeding further it will be necessary to show how the value and distribution of the charge upon a telegraph line may be represented.

GRAPHIC REPRESENTATION OF THE CHARGE UPON A LINE.

The quantity of electricity or the charge upon a disconnected telegraph circuit is equal to the product of its capacity and the E.M.F. applied to it. If, therefore, the capacity is numerically represented by the length of a horizontal line and the E.M.F. by the height of a vertical line, the quantity of the charge will be represented by the area of the rectangle contained by those lines. Moreover, the direction of the charge, positive or negative, may be shown by drawing the rectangle respectively above or below the horizontal line. If an E.M.F. of one volt is represented by a vertical line one inch long and a farad by a horizontal line one inch long, the area enclosed is one square inch, and this would represent one coulomb. Any values of E.M.F. and capacity could readily be plotted, and the enclosed area in square inches would represent the value of the charge in coulombs. In the present case, however, it is only desired to show the relative magnitudes and distribution of charges, and therefore 50 volts and $\frac{1}{2}$ m.f. will respectively be represented by $\frac{3}{4}$ and $\frac{7}{20}$ inch. The value of the charge in coulombs will then be equal to $\cdot 000\dot{2}$ of the area enclosed (in square inches). The farad and coulomb are, of course, far too large units for practical purposes, and in this instance each square inch of area will represent 222 micro-coulombs.

The charge due to an E.M.F. of 50^v applied to a circuit of 5 m.f. capacity is shown in Fig. 141. The area of the shaded portion represents the value of the charge, and, as it is shown above the line, the sign is positive. Since the wire is disconnected the same difference of potential exists between line and earth at both ends of the circuit. The charge is due to a current flowing from the positive pole of the battery, to the side of the dielectric in contact with the line, and from the dielectric in contact with the earth back to the negative pole of the battery. If the battery be now disconnected and the wire earthed, the charge will flow out of the wire to earth and so relieve the strain upon the dielectric (vide page 228).

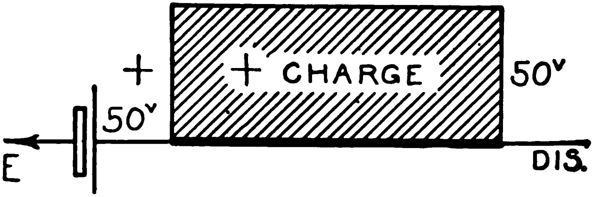

Fig. 141.—Positive charge upon a disconnected line.

An E.M.F. of 50^v is shown applied in the reverse direction to an earthed circuit of 5 m.f. capacity in Fig. 142. In this case the potential of the positive pole of the battery is zero, *i. e.* the same as that of the earth, whilst that of the negative pole is 50 volts below zero. At the battery end the difference of potential between the wire and earth is 50 volts, but at the other end it is nothing, since that end is earth connected. The charge is therefore represented in value by the area, and in sign by the *downward position* of the triangle. It will be seen that, with the same E.M.F. applied in both cases, the value of the charge upon an earthed circuit is half that upon the circuit when disconnected. It will also be noted that the charge is not evenly distributed over the wire but is densest at the battery end and at the distant end is nothing. The density therefore varies from nothing at the earthed end to a maximum at the battery end, due to the fact that the difference of potential similarly varies from nothing to −50 volts.

The effect of connecting two earthed batteries in series at either end of a circuit is shown in Fig. 143. The differences of potential between each end and earth is +50 volts and −50 volts respectively. It will therefore be seen that at the centre of the circuit the potential is zero, and no effect would be produced upon the magnitudes and values of the charges if that point were earthed. It will also be noticed that the disconnection of the right-hand battery would reproduce the conditions of Fig. 141, and that a current would flow into the wire sufficient to sweep out the negative charge and to charge the whole of the wire positively.

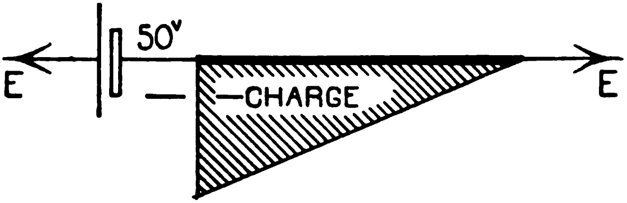

Fig. 142.—Negative charge upon an earthed circuit.

The results of the foregoing somewhat lengthy explanations may be summarized as follows, and it is in this form that they will be applied to the practical cases which present themselves.

1. The value and sign of a charge may be represented by the area of a rectangle or triangle as the case may be.

2. If either pole of a battery is earthed its potential is

considered zero, and that of the other pole as the E.M.F. of the battery above or below zero as the case may be.

3. The potential of the earthed end of a circuit is considered as zero.

PATHS OF LINE AND COMPENSATION CIRCUIT CHARGES AND DISCHARGES.

When both keys of a double current duplex set are at rest opposite poles of the battery are connected to the line at the two ends and the distribution and signs of the charges are therefore similar to those depicted in Fig. 143.

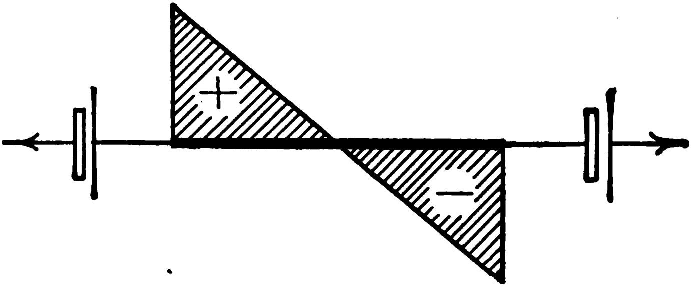

FIG. 143.—Positive and negative charges due to connecting earthed batteries of equal E.M.F., but with their opposite poles connected to the two ends of the circuit.

At the down station the positive pole of the battery is normally connected to line, but in Fig. 144 the key is shown depressed, *i. e.* with negative to line. The two shaded triangles represent the charges which exist when both keys are at rest. If the down station key were depressed, the negative pole of the battery would be connected to line as shown in the figure. It is, however, desired to trace exactly what happens at the moment of depressing the key, and therefore the charges which existed when both keys were at rest have been depicted as stated. The up end of the line is negatively charged and the reversal of the battery at the down end will clearly produce a negative charge at that end also. Since the two batteries are of equal E.M.F. the potential below the earth will be the same, and the result will be that the wire will have the negative charge depicted by the rectangle enclosed by the wire, dotted lines, and the full line at the up end. In order to effect this, the existing positive charge at the down end must be swept out and a negative charge must be given of sufficient value to complete the negative charging of the wire. It should be noticed that the negative charge at the up end of the circuit remains the same, and it is merely a matter of "filling up" the rest of the wire with negative.

Having dealt with the charge when both keys are at

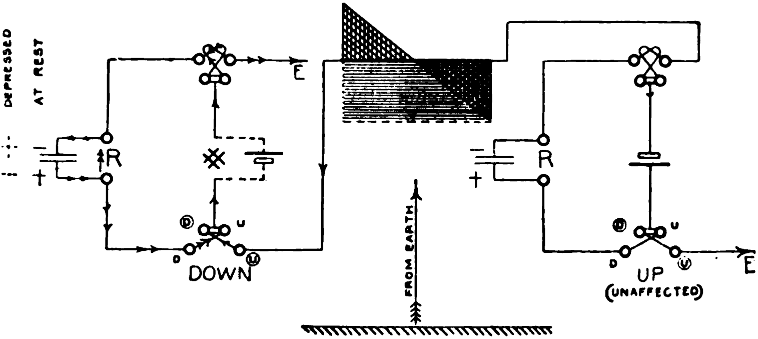

Fig. 144.—Double current duplex. Paths of line and condenser charge and discharge. The conditions are depicted at the moment when the down key is depressed.

rest and when the down key only is depressed it is necessary to trace the direction of the charges and discharges which must occur in order that the former condition may merge into the latter. In order to charge the wire negatively a current must flow from the positive to earth to the dielectric in contact with the earth, and an equal quantity must flow from the other side of the dielectric to the wire and back to the negative pole of the battery. If the wire possesses a positive charge the direction of its discharge is the same, viz. from the wire to earth through and in the same direction as the battery. In the present case, therefore, the depression of the down key (as shown in Fig. 144) causes the positive charge to discharge through the battery. The negative recharge of course takes place in the same direction. A positive discharge and a negative recharge current therefore flow from the wire through the *U*-circle *D*-circle coil of the relay (direction *U* to *D*), through the battery, right coil of the galvanometer, to earth. This may be put in another and more correct way. Upon reversing the battery a current flows from the positive pole through the galvanometer to earth, to the dielectric (air, paper, or gutta-percha as the case may be), in contact with the earth, then from the other side of the dielectric in contact with the wire, on to the wire, out of the wire at the down end, through the circle coil of the relay, back to the negative pole of the battery. The current flows until the whole of the wire is negatively charged, and therefore the quantity of electricity flowing out of the end of the wire to earth through the apparatus is equal to the product of the E.M.F. of the battery, and the capacity of the circuit when disconnected at the distant end. This will be quite apparent from the fact that the charges existing when both keys were at rest are equal in magnitude, but opposite in sign.

The terminals of the rheostat are bridged by a condenser of such a capacity that its discharge and recharge in the reverse direction through the compensation coils of the relay and galvanometer are equal to the discharge and recharge of the line through the other coils. When both keys are at rest the condenser at the down station is charged by the difference of potential across the terminals of the rheostat; due, of course, to the current flowing in the compensation circuit. The lower plate is therefore charged positively and the upper negatively. When the down key is depressed (as depicted) the condenser discharges and is charged in the reverse direction, the result being indicated by the dotted signs. There are two paths open to the discharge current, viz. through the rheostat and through the *D U* coil of the relay, battery, and left coil of the galvanometer. By far the greater portion takes the latter path and is followed by the recharge in the reverse direction. In fact, no serious error is made in assuming that the whole of the discharge and recharge occurs through the relay and galvanometer, and that practically no current flows through the rheostat until the condenser is fully charged with the quantity of electricity it will require to have due to the potential difference between the terminals of the rheostat. The charges in the condenser at the up end are unaffected because that battery has not been disturbed, and therefore the potential difference across its rheostat is unaltered in magnitude or direction. Both the condenser and the line discharges and recharges are caused by the reversal of the battery, and the circuit from the strapped galvanometer to the strapped relay terminals is common to both. The directions and paths of the line and condenser charges have respectively been indicated by single and double arrow-heads. The effect of the line charge is to produce a marking "kick" on depressing the key and that of the compensation circuit a spacing "kick" and, by choosing a suitable value of capacity in the condenser, the two effects counterbalance each other and duplex working is possible.

As the above conditions have received such minute consideration it will suffice briefly to state the effects due to depressing or raising the other key and then to summarize the whole of the results of the investigation.

If the down key is released the conditions of charge represented by the triangles will be re-established and the condenser will be discharged and recharged as indicated by the full and not the dotted signs. This will entail rushes of current in the down station's line and compensation circuits in directions opposite to those shown by the arrow-heads. The up station will be unaffected.

The depression of the up key whilst the down key is at rest will cause the whole of the line to be positively charged and will reverse the charge in the up condenser. The path of the line negative discharge and positive recharge is from the positive pole of the battery through the line coil of the galvanometer to line into the adjacent dielectric, thence from the opposite side of the dielectric to earth, through the relay from *U*-circle to *D*-circle and back to the negative pole of the battery. The condenser discharges and recharges through the other coils of the galvanometer and relay, but in the spacing direction. The down station is unaffected. When the up key is released the conditions previously existing are restored by discharges and recharges in the opposite direction to those just described.*

SUMMARY OF EFFECTS OF LINE AND COMPENSATION CIRCUIT CHARGES AND DISCHARGES.

The results of the foregoing investigations may be summarized as follows:—

1. At the end of the circuit, where the position of the key is unaltered, no effect takes place, and it is therefore only necessary to consider the end where the key is changed in position.
2. The sign of the charge upon the end of the line is the same as that of the pole of the battery connected to it.
3. The discharge and recharge of the line is in the same direction as the discharge and recharge of the condenser, and both are always in the same direction as the E.M.F. of the battery when the latter is changed by altering the position of the key.
4. The line discharge and recharge passes through the line coils of the relay and galvanometer and through the battery.
5. The compensation circuit charges and discharges through the left coil of the galvanometer, battery, and *UD* coil of the relay.
6. On depressing a key the direction of the line discharge and recharge is from *U*-circle to *D*-circle, so tending to cause a marking kick. The galvanometer needle similarly upwards or towards the right.

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* The reader is strongly advised to sketch each of the conditions dealt with, and to plot the resulting charges together with the paths of the current producing them.

ARRANGEMENT OF COMPENSATION CIRCUIT FOR BALANCING LONG LINES.

Upon page 266 it was stated that very long lines could not be satisfactorily balanced by simply placing a condenser across the terminals of the rheostat. It will now be necessary to investigate this statement and consider the arrangements adopted in such cases.

The quantity of electricity in a given condenser depends upon the E.M.F. with which it was charged and upon its capacity. The discharge of the condenser will give rise to a current of electricity, but the duration and magnitude of the current will depend upon the properties of the circuit through which it discharges. For instance, the condenser will take twice as long to discharge itself through a resistance coil of 100ω as it would through a 50ω coil. In the former case the average value of the discharge current would be only half as much as in the latter case.

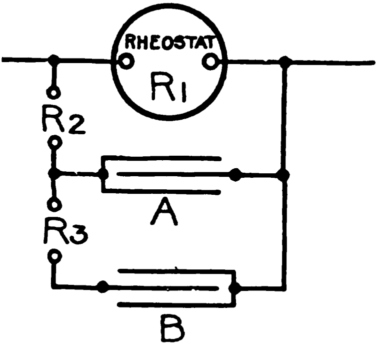
In order that the discharge of the condenser in the compensation circuit may balance that in the line circuit, it is obvious that the discharges must not only be equal as regards the quantity of electricity discharged, but the discharges must occupy exactly the same time. In fact, at any and every instant during which the two discharges take place they must be exactly equal in value. Now the charge and discharge of a long line cannot be balanced by a compensation circuit arranged as in Fig. 144. The quantity of electricity discharged through the line coils of the galvanometer and relay may be exactly equal to that discharged through the compensation coils, but unless the rate of discharge is the same, irregularities will inevitably occur. The line charge and discharge are slow in comparison with the charge and discharge of a condenser arranged as described. The reason is that in charging a line, say a hundred miles long, the current has to traverse and charge the first ten miles before it can charge the second, the second ten miles of line has to be traversed and charged by the current before the third ten miles is charged, and so on. The resistance encountered in the path of the charging current slows down the rate at which the circuit is charged. In the case of the condenser the battery is applied almost directly to its termimals and the charge is therefore much more rapid. In the one case the capacity is distributed over a very long line, every mile of which has a very appreciable resistance, whilst in the other the capacity is all located at one point and that point almost directly between the terminals of the charging battery. The one coil of the relay, and the one coil of the galvanometer alone intervene between the terminals of the battery and the condenser.

EFFECTS OF DEFECTIVE CAPACITY BALANCE.

It will now be possible to trace the effect of attempting to balance a long line by a condenser bridged across the rheostat. In Fig. 144 the paths and directions of the line and condenser discharge and recharge upon depression of the down key are indicated by arrow-heads. If the line is very long, its discharge and recharge will occupy a longer time than that of the condenser. The rapid charging of the condenser will give rise to a short heavy current, whilst the slow charging of the line will entail a smaller current spread over a longer time. Therefore the charge current through the compensation circuit will, during its existence, preponderate over the line charge current, so causing a kick to spacing. Immediately the short heavy charge of the condenser ceases the line charge, which is still proceeding, in its turn affects the relay, but in the opposite direction. The result of the arrangement is that the two charge currents alternately upset the balance, but the unopposed latter part of the line charging current is of very small importance in comparison with the preponderance of the short heavy rush of current through the condenser.

The introduction of resistance into the charging and discharging circuit of a condenser slows down its rate of charge and discharge. If, for instance, an E.M.F. of 100 volts is applied to a condenser in series with a resistance of $10,000^{\omega}$, it will be obvious that the maximum possible value of the charging current at the instant at which the charge commences cannot possibly exceed 10 m.a. $\left(\frac{E}{R}\right)$. If the resistance is 1000^ω, upon the same argument the maximum current could not exceed 100 m.a.

The insertion of resistance between the condenser and the rheostat has, then, the effect of slowing down the charge and discharge of the condenser. It will not however, in any way affect the *quantity* of electricity in the condenser.



145.—Arrangement of condensers and timing resistances in the compensation circuit.

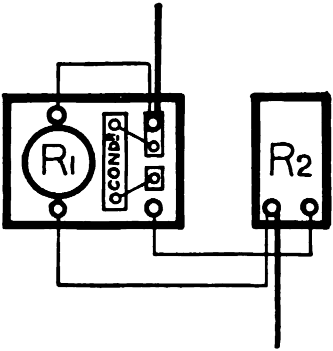


FIG. 146.—Arrangement for balancing apparatus in compensation circuit. R_1 is the rheostat, R_2 the retardation coils, and R_3 (Fig. 145) and the coils marked "condr." (Fig. 146) are the condenser coils.

RETARDATION AND CONDENSER COILS.

Upon very long circuits even this device fails, and recourse is taken to the use of two condensers and two resistances as depicted in Fig. 145. The first condenser *A* is charged and discharged through the resistance R_2 and the second condenser *B* through both R_2 and R_3. The charge and discharge of the second condenser therefore occur a little later than those of the first, and the result is a much closer imitation of the line charge and discharge than is possible with a single condenser. The two condensers are contained in a single box as described in

Chapter VII. A reference to this and to Figs. 145 and 146 will make the arrangement adopted quite clear.

The resistance R_2 is termed the retardation coils and is furnished with eight coils having a total maximum of 1100^{ω}, the smallest coil being 10^{ω}. The resistance R_3 is only employed upon circuits over 150 miles in length, and for circuits under 200 miles long consists of a fixed resistance coil of 2000^{ω}. Over that length a 7-plug resistance box, having a range of 50^{ω} to 4050^{ω} by gradations of 50^{ω} is employed, and is termed the "condenser coils." Since the resistance required in the condenser coils varies to a very small extent with the weather, the fixed resistance coil 2000^{ω} is quite satisfactory upon any but the longest circuits.

For cable circuits it is necessary to employ a three-section or triple condenser of considerable capacity and three sets of resistance coils, but the principle of the arrangement is identical with that of the two-section condenser.

CAPACITY BALANCE MAY DIFFER AT THE TWO STATIONS.

In Fig. 144 the capacity and resistance of the line were assumed to be uniformly distributed along the length of the line. In practice this is rarely the case, especially upon long circuits. The effect of an unequal distribution is to alter the position of the zero point. To take a greatly exaggerated case, suppose that a line has a resistance of 2000^{ω}, and that one-half of the circuit has a capacity of 15 m.f., whilst the capacity of the second half is nothing. Such a case could be artificially produced by adding a resistance coil to a long underground circuit, the value of the coil being equal to the conductor resistance of the line. The zero point of the circuit would be at the junction of the line and the coil. Since there is no charge upon the artificial resistance, it will be found that the effect of reversing the key at the resistance coil end of the circuit is to cause a charge proportional to the area of the triangle representing the charge to occur. At the cable end, reversal of the key results in a discharge exactly three times as great. This deduction from the principles already considered is so obvious that further explanation should not be needed.

The application of this principle in practice shows that where a circuit consists of a submarine or long underground line at one end, with an open line of considerable length joining it, the capacity at the open end of the circuit may be very much less than that at the cable end. For instance, upon a London Birmingham duplex passing through the underground route, 7¼ m.f. condensers are required at either end. If the circuit is extended northwards from Birmingham by a long open line, a 10½ m.f. condenser is needed at the London end.

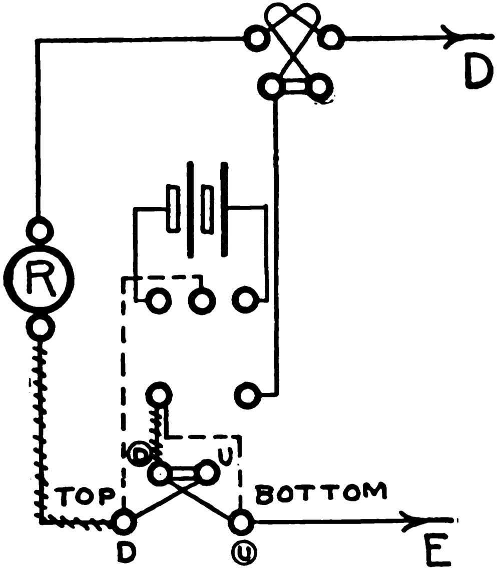


FIG. 147.—Alterations to double current duplex connections required for simplex working. The scored connections are required for duplex, and the dotted connections for simplex working.

At the cable end of a circuit the value of the retardation resistance is usually low, and the capacity in the first division of the condenser is correspondingly high.

CONNECTIONS OF DUPLEX SET.

A duplex and single switch is added to the apparatus in much the same way as in the single current duplex. The alterations required to change the set from duplex to simplex are shown in Fig. 147. The dotted lines represent the connections which must be established and the scored lines those which must be broken. Figs. 134 and 147 should be carefully compared, and little trouble will then be experienced in remembering the connections. The full connections are depicted in Fig. 148.

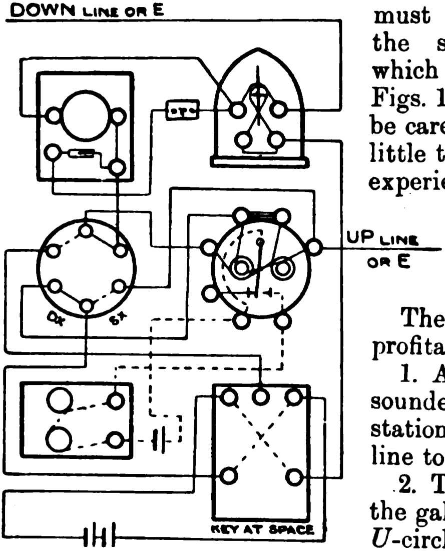


FIG. 148. – Double current sounder duplex connections.

The following facts may profitably be noted :—

1. As in all types of sounder circuit, the up station sends positive to line to mark.
2. The right terminal of the galvanometer and the *U*-circle terminal of the relay are respectively the down and up line terminals.
3. The top three terminals of the duplex switch deal with *D* of the relay, and the lower three with the left terminal of the key.
4. The key is inserted between the strapped terminals of the galvanometer and relay.
5. With the keys at rest the line, or circle, coils tend to space.

DOUBLE CURRENT DUPLEX WITH POLARIZED SOUNDERS.

The connections are similar to those of Fig. 148, but the polarized sounder ($500^{\omega} + 500^{\omega}$) takes the place of the relay. The compensation circuit is shown with a "*D*" rheostat, and both retardation and condenser coils.

RESISTANCE BALANCE.

It has previously been stated that the resistance of a conductor varies with its temperature. The conductor resistance of a telegraph circuit therefore varies from day to day, and the difference between its resistance at summer and winter temperature (100° F. and 22° F.) would amount to 26½ % if the wire were of iron and to nearly 18 % if of copper wire erected upon poles. The insulation resistance of the circuit is also subject to wide variations. In very fine dry weather the insulation rises to a very high value, and in damp or wet weather falls to a corresponding extent. Upon long circuits this difference is most distinctly felt, but upon very short circuits it is not noticeable, because of the disparity in the values of the conductor resistance and the lowest value of the insulation resistance without the existence of a definite fault or faults. This point will not, perhaps, be clearly apprehended until Chapter XXI has been considered.

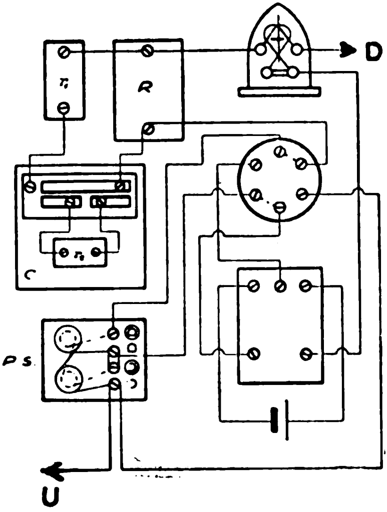


FIG. 149.—Double current duplex with polarized sounders.

Since the resistance of a circuit is variable, it will be seen that an adjustable resistance and not a resistance coil of fixed value must be employed to balance it. The instrument employed, termed a rheostat, has been described in Chapter III. The value of the resistance which it is necessary to insert to obtain a balance is ascertained by means of the duplex set itself.

The top of the needle of all Post Office galvanometers deflects in the direction in which the effective current passes from terminal to terminal of the instrument, and reference to Figs. 139 and 140 will, by aid of this rule, show that a spacing current is represented by a deflection to the left, and a marking current by a right deflection. In Fig. 139 both needles deflect to the left, and the relay spaces by the preponderance of current in the line coils of the galvanometer and relay. This fact may be expressed in an equally correct but more convenient way, viz. that they are actuated by the current received from the distant station. If a resistance coil equal in value to the internal resistance of the battery is substituted for the distant battery, the deflection upon the home galvanometer at once falls to zero if the circuit has been accurately balanced. The home current divides equally between the line and compensation circuits, and no effect is therefore produced. If these circuits were not balanced then the one of lower resistance would carry the larger current, so producing a deflection, the direction of which would be reversed upon depression of the key. The effect of replacing the resistance coil by the distant battery may be regarded as the sending of a current through the home line coils of galvanometer and relay. This spacing current deflects the galvanometer and causes the relay to space, but if the home key is now depressed the deflection upon the home galvanometer is increased or decreased according to which circuit (line or compensation) has the higher resistance.

If no resistance is inserted in the rheostat the compensation current is sufficiently great to overcome the effect of the current in the line coils of the relay and galvanometer, and a marking current and deflection will result. The sounder will be held down, and the marks sent upon the home key will be received reversed upon the home sounder. Upon the other hand, a disconnection or the insertion of a very large resistance in the rheostat will cause the marks from the home key to be received straight.

The practical operation of balancing is carried out by the aid of the effects which have been explained above. The 40^{ω} arm of the rheostat is placed at zero, and the 400^{ω} arm at any value in excess of the resistance of the circuit. The key is depressed, and the effect observed upon the galvanometer or the sounder if the balance is out to a sufficient extent to affect it. The 400^{ω} arm is moved downwards, point by point, until the depression of the key gives a deflection in the reverse direction to that previously obtained. The 40^{ω} arm is then moved up point by point until a balance is obtained. An increased downward deflection (or, if the needle lies on the marking side, a reduced or reversed deflection) upon depression of the key indicates that the resistance in the rheostat should be increased, and the converse that it should be reduced. The use of this rule in a logical manner enables a circuit to be accurately balanced in the minimum of time.

CAPACITY BALANCE.

The balancing of the capacity of the circuit can only be effected when the resistance has been dealt with, and it will now be necessary to point out that the resistance balance is obtained by noting the position of the galvanometer needle when the kicks due to inaccurate capacity balance have passed away. It is merely necessary to hold the key down sufficiently long for the needle to come to rest after the kick has passed away. The steady positions of the needle should alone be observed in this case.

The effects of capacity have been very fully considered, and the following rules can readily be deduced from the previous explanation :—

1. If, on depressing the key, the galvanometer needle momentarily deflects upwards (*i. e.* marking direction), the capacity in the compensation circuit should be increased.

2. If, on depressing the key, the galvanometer needle momentarily deflects downwards (*i. e.* spacing direction), the capacity in the compensation circuit should be decreased.

3. If, on depressing the key, the galvanometer needle

momentarily deflects upwards, and upon releasing the key again momentarily deflects in the same direction, the timing resistances (retardation and condenser coils) require alteration.

In cases (1) and (2) the kick is observed in the reverse direction when the key is released. The final adjustments are frequently made by the passage of working signals, and resolve themselves into an intelligent form of "trial and failure" method. The time taken in finding the exact balance of a cable circuit upon which a triple condenser is employed is very considerable, but when once found the variations necessitated from it are confined within small limits.

The second and third retards very rarely require alteration, but the first retard (retardation coils) is extremely important.

BATTERY POWER AND CURRENT REQUIRED.

The current required is from 14 to 17 m.a., and is calculated for the conditions of simplex working, No. 1 cells being used. The local battery is a three-cell Leclanché No. 1.

CHAPTER IX

THE QUADRUPLEX.

QUADRUPLEX working consists in the simultaneous transmission of two messages in each direction over a single wire connecting two stations. It is accomplished by taking advantage of the fact that currents may differ from each other in direction and in strength. Two keys are employed, viz. the reversing or *A* key which determines the direction of the current, and the increment or *B* key which determines its strength. One of the two relays used in conjunction is polarized and the other non-polarized. The polarized relay is of the Post Office Standard *B* pattern, in which the tongue is, of course, only moved over to *M* when the current passes in the direction *U* to *D*. The non-polarized relay, upon the other hand, is actuated by a current in either direction provided that it is sufficiently strong to overcome the pull of the antagonistic spring. This relay is so adjusted that unless the strength of the current is increased by depression of the increment key its armature is unaffected. The polarized relay is affected only by a current in the direction *U* to *D* which occurs solely when the reversing key is down.

It will therefore be seen that the two relays may be selectively actuated by the two keys. By depressing the reversing key a current passes through the relays in the direction *U* to *D*, but it actuates the polarized relay only, its strength being insufficient to overcome the pull of the spring upon the non-polarized relay. Depression of the increment key alone actuates the non-polarized relay only, because the current passes in the direction *D* to *U*. If both keys are down a current of full strength passes through both relays in the direction *U* to *D*, and both are therefore actuated.

The whole arrangement is duplexed upon the differential principle by splitting the sending currents equally through the differentially wound relays and galvanometer. The details of the instruments will, however, be reserved until the working of the set as a whole has been considered.

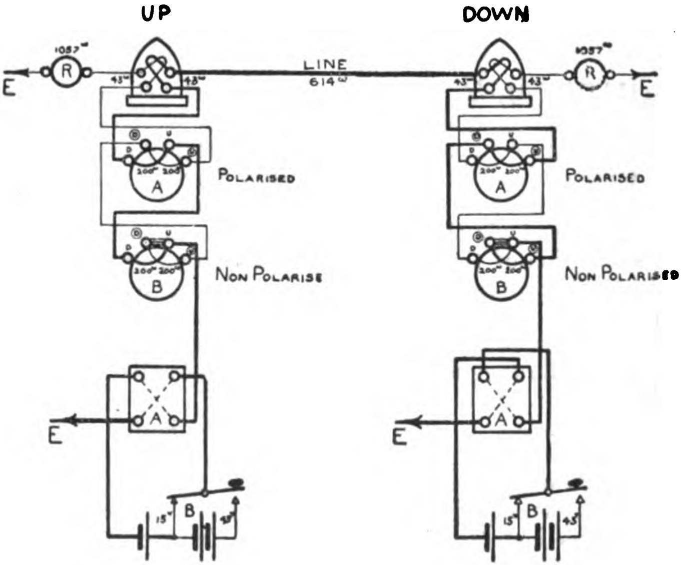


Fig. 150.—Principle of Quadruplex.

Skeleton Connections.

The skeleton connections of a quadruplex set are depicted in Fig. 150. The reversing key is a double current key with its switch at send. The increment key is here represented by an ordinary single current key, and at present calls for no further comment. The negative pole of the battery is joined to *Z* of the reversing key, and *C* is taken to the centre of the increment key. When this key is at rest only a part of the battery is connected to the reversing key, but when it is depressed the whole battery is so connected. The reversing key controls the direction of the current and the increment key its strength.

The left side of the reversing key is earthed and the right side goes to the split of the non-polarized relay. The right-hand coil of the galvanometer, the plain coil of the *A* side relay and the same coil of the *B* side relay are connected in series to the line at the up station. The other coils of the two relays and galvanometer are similarly joined in series to the rheostat which contains resistance equal to that of the line and distant apparatus.

When all the keys are at rest the conditions which obtain are similar to those of a double current duplex, viz. the batteries at the two stations combine together to produce a current in the line circuit twice as large at that in either of the compensation circuits. This preponderating current must be in the spacing direction, and in order to effect this and the combination of the batteries, the connections at the down office have to be modified. Firstly, to effect the combination of the batteries the two battery wires upon *Z* and *C* of the reversing key are crossed, and secondly, the line and rheostat change sides of the galvanometer, and thus a spacing effect is normally produced at the down office.

VALUE OF THE CURRENT UNDER VARIOUS CONDITIONS.

The working of the set will be most clearly understood by giving definite numerical values to the various factors which determine the currents in the various parts of the circuit. With the *B* key at rest an E.M.F. of 15 volts is connected to the *A* key, and with the *B* key depressed this E.M.F. is raised to 45 volts. The battery has been assumed to have no internal resistance in order to simplify the calculations involved. This assumption does not involve any appreciable error in the general results which will be obtained, but it will subsequently be indicated how far these results must be modified to accord with strict accuracy. The resistances of the remaining parts of the circuit are clearly marked upon the diagram (Fig. 150).

The total resistance of the line circuit is $200 + 200 + 43 + 614 + 43 + 200 + 200 = 1500^{\omega}$. The resistance of either compensation circuit is $200 + 200 + 43 + 1057 = 1500^{\omega}$ (vide page 292).

Condition 1.—With all the keys at rest the path of the line circuit current is from the positive pole of the 15-volt up battery to earth, through and joining with the 15-volt down battery through the line coils of both relays (direction *D* to *U*) and the galvanometer, along the line through the line coils of the up galvanometer and relays (*D* to *U*) and thence back to the negative pole of the battery. The current in this circuit is produced by $15 + 15 = 30$ volts, and is therefore $\frac{30}{1500} = 20$ m.a. The compensation currents are each $\frac{15}{1500} = 10$ m.a. and in the direction *U* to *D*, consequently both *A* relays are held to spacing by the 10 m.a. preponderance of the line current from *D* to *U* in the relay. The *B* relays are unaffected because they are adjusted to be unaffected by a preponderance of 10 m.a.

Condition 2.—With both *A* keys down both *A* relays will mark due to the reversal of the current.

Conditions 3 *and* 9.—With one *A* key down and one at rest the batteries oppose and their compensation circuits respectively space and mark with the 10 m.a. which their own batteries produce in them. As stated above, this current of 10 m.a. upon one coil of the relay is not sufficient to actuate the *B* relays.

Condition 4.—If both *B* keys are depressed an E.M.F. of 45 volts is connected to the *A* key at each end. With both the *A* keys at rest the paths and directions of the currents are identical with those described when the *B* keys were also at rest. The strength of the current in each part of the circuit is, however, three times as great.

$$\text{Line circuit current} = \frac{45 + 45}{1500} = 60 \text{ m.a.}$$

$$\text{Current in each compensation circuit} = \frac{45}{1500} = 30 \text{ m.a.}$$

The current in the line coils of both stations' relays is from *D* to *U* and therefore both *A* relays space, but the *B* relays, being non-polarized, both mark due to the effect of $60-30=30$ m.a. upon one coil of the relay.

Condition 16.—This is as in Condition 4, but with the currents in the reverse direction. All four relays are actuated.

Conditions 5 *and* 15.—If an *A* key is depressed whilst both *B* keys are still down the batteries oppose each other in the line circuit, and the compensation circuits are therefore left unopposed to produce their effects. Each carries a current of 30 m.a. produced by the full power, and therefore both *B* relays are actuated. At the end where the *A* key is depressed the current is in the direction *D* to *U*, and therefore the *A* relay spaces, but at the distant end a mark is registered because the compensation current is there flowing in the *U* to *D* direction.

Conditions 6 *and* 11.—One *B* key only is depressed. The E.M.F. acting in the line circuit is $15+45=60^{v}$, and the current is therefore $\frac{60}{1500}=40$ m.a. The direction of the line current is from *D* to *U* and is produced by the batteries acting together. At the end where the *B* key is depressed the compensation current is $\frac{45}{1500}=30$ m.a., and the net effect at that end is therefore $40-30=10$ m.a. in the direction *D* to *U* through both relays. Both these relays therefore space. At the distant end the compensation current is produced by the smaller E.M.F. and is $\frac{15}{1500}=10$ m.a. in the direction *U* to *D*. The nett effect is therefore $40-10=30$ m.a. upon the line coils of the relays. This actuates the *B*, but not the *A*, relay because the direction of the preponderating line current is from *D* to *U*.

Conditions 7 *and* 12.—One *A* key and the distant *B* key depressed. Let the up *B* key and the down *A* key be depressed. The current in the line circuit is due to the larger up battery sending a current through the smaller down battery. This current is equal to the difference in the E.M.F.s divided by the resistance of the line circuit. It is $\frac{45-15}{1500} = 20$ m.a. in the direction *D* to *U* at both ends. The compensation currents at the down and up offices are respectively 10 m.a. direction *D* to *U*, and 30 m.a. direction *U* to *D*. At the up office the difference between the compensation and line currents is $30-20=10$ m.a. in the direction *U* to *D*. The up *A* relay therefore marks, but the *B* relay is unaffected. At the down station the line current (20 m.a.) flows through both relays in the direction *D* to *U*. The current in the compensation circuit is 10 m.a. and in the same direction, viz. *D* to *U*. The effects of the line and compensation currents (20 m.a. and 10 m.a. respectively) are therefore added together, and are equivalent to 30 m.a. upon one coil of the relay. The *A* relay is unaffected, but the *B* relay is actuated. References to the skeleton diagram given in Fig. 151 will serve to make matters clear.

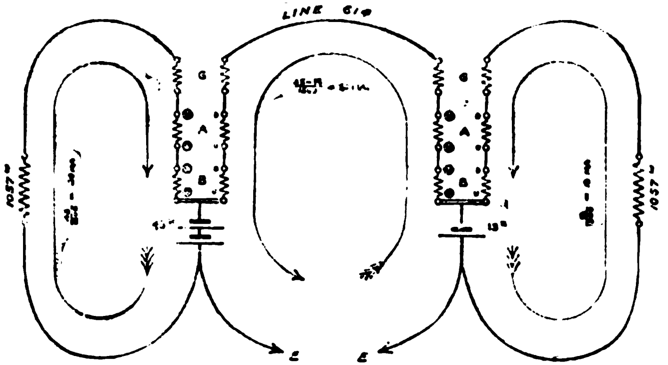


Fig. 151.—Currents in a quadruplex circuit with the down *A* key and up *B* key depressed.

In explaining the above condition it was stated that the larger battery sent a current of 20 m.a. through the smaller one. This statement is scarcely correct since the smaller battery is at the same time assumed to be sending a current through its compensation circuit. The numerical values of the currents obtained by the assumption are accurate, but the actual path of the current is this: the 20 m.a. flowing through the line circuit divides into two equal parts when it reaches the split of the relay, one of which parts flows through the battery in opposition to its E.M.F. and the other half flows round the compensation circuit.

A schedule showing all the possible combinations of the positions of the keys and the resulting conditions is given on page 292.

SUMMARY OF QUADRUPLEX CONDITIONS.

I. *Conditions* 1, 2, 3 *and* 9 are precisely similar to an ordinary double current duplex circuit with 15^v batteries and a line and compensation circuit resistance of 1500^ω.

II. *Conditions* 4, 5, 15 *and* 16 are precisely similar to an ordinary double current duplex circuit with 45^v batteries and a line and compensation circuit resistance of 1500^ω.

III. *Conditions* 6, 10, 11 *and* 14.—In these cases the *A* battery at one end combines with the *B* battery at the other end, with the result that at the end where the *B* key is depressed the net effect is that of the *A* current, whilst at the other end a preponderance equal to the *B* current results.

IV. *Conditions* 7, 8, 12 *and* 13.—In each instance the *A* battery opposes the distant *B* battery. At the end where the *B* key is depressed the compensation circuit preponderates to the extent of the value of the *A* current. whilst at the other end the line and compensation current effects add together and so actuate the *B* relay.

THE "B KICK."

A serious difficulty arises in quadruplex working owing to the fact that the reversal of the current through the circuit by the *A* key occupies a definite interval of time,

QUADRUPLEX CONDITIONS.

Condition	Position of Keys				Compensation Circuit				Line Circuit		Nett Effect				Result				Effect due to Line or Compensation Circuit	
	Up		Down		Up Circle Coil		Down Plain Coil		Up Plain Coil Down Circle Coil		Up		Down		Up		Down		Up	Down
	A	B	A	B	Current	Direction	Current	Direction	Current	Direction	Current	Direction	Current	Direction	A	B	A	B		
1	|	|	|	|	10	UD	10	UD	20	DU	10	DU	10	DU	S	S	S	S	L	L
2	×	|	×	|	10	DU	10	DU	20	UD	10	UD	10	UD	M	S	M	S	L	L
3	×	|	|	|	10	DU	10	UD	0	—	10	DU	10	UD	S	S	M	S	C	C
4	|	×	|	×	30	UD	30	UD	60	DU	30	DU	30	DU	S	M	S	M	L	L
5	×	×	|	×	30	DU	30	UD	0	—	30	DU	30	UD	S	M	M	M	C	C
6	|	×	|	|	30	UD	10	UD	40	DU	10	DU	30	DU	S	S	S	M	L	L
7	|	×	×	|	30	UD	10	DU	20	DU	10	UD	30	DU	M	S	S	M	C	L+C
8	×	×	|	|	30	DU	10	UD	20	UD	10	DU	30	UD	S	S	M	M	C	L+C
9	|	|	×	|	10	UD	10	DU	0	—	10	UD	10	DU	M	S	S	S	C	C
10	×	×	×	|	30	DU	10	DU	40	UD	10	UD	30	UD	M	S	M	M	L	L
11	|	|	|	×	10	UD	30	UD	40	DU	30	DU	10	DU	S	M	S	S	L	L
12	×	|	|	×	10	DU	30	UD	20	DU	30	DU	10	UD	S	M	M	S	L+C	C
13	|	|	×	×	10	UD	30	DU	20	UD	30	UD	10	DU	M	M	S	S	L+C	C
14	×	|	×	×	10	DU	30	DU	40	UD	30	UD	10	UD	M	M	M	S	L	L
15	|	×	×	×	30	UD	30	DU	0	—	30	UD	30	DU	M	M	S	M	C	C
16	×	×	×	×	30	DU	30	DU	60	UD	30	UD	30	UD	M	M	M	M	L	L

The continuous depression of the *B* key actuates the distant *B* relay, and if, whilst this mark is proceeding, the *A* key be depressed and released, breaks will occur in the signal each time the position of the *A* key is changed. The *B* relay is not affected by the *A* current, say 15 m.a., and assuming that it will be actuated by 17 m.a. only, then the spring of the *B* relay will pull the tongue of the relay away from the marking contact from the instant at which the current falls below 17 m.a. until it rises again to 17 m.a. in the reverse direction. The time taken for the current to fall from its maximum value to zero and then to rise to its maximum value in the reverse direction is proportional to the product of the capacity and resistance of the circuit (see page 628). But, in addition to this, there is also the time occupied by *A* key in reversing the direction of the current; this can, however, be reduced to a minimum by carefully adjusting the contacts of the *A* key so that there is an instant in which the lever is just touching both upper and lower contact springs.

It will therefore be recognized that there is an interval of time during which the spring of the *B* relay pulls the tongue away from the marking stop, thus producing a break in the *B* signal. This effect, generally termed the "*B* kick," must be counteracted before quadruplex working is possible. Quadruplex working is, then, practicable only when these intervals of break in the *B* signals due to the change in position of the *A* key are bridged over and the various quadruplex systems which have from time to time been devised differ principally in the device adopted to counteract the "*B* kick."

The currents due to the *A* key sending the letter "a" whilst the *B* key is sending a dash are shown graphically in Fig. 152. The direction and magnitude of the currents are indicated by the position and height of the rectangles above or below the zero line, and the duration of the currents by the length. Whilst the *A* key is sending the first dot *ac* the *B* key also is depressed at *b*, thus raising the current from 15 m.a. to 45 m.a., and it will first be assumed that the current rises to its full value and reverses instantly. At *c* the *A* key is released, the key short-circuits the battery momentarily and then joins it up in the reverse direction. With a badly adjusted key, *i. e.* one in which there is either a comparatively long interval between the moment at which the battery is short-circuited prior to connection in the reverse direction, an interval of time, *cd*, comparable in this instance with a quarter of the length of a dot, elapses before the full current is re-established in the reverse direction. During this time the *B* relay is unmagnetized, and the spring therefore breaks the mark from c^1d^1. The mark is again broken at e^1f^1 when the *A* key again changes position.

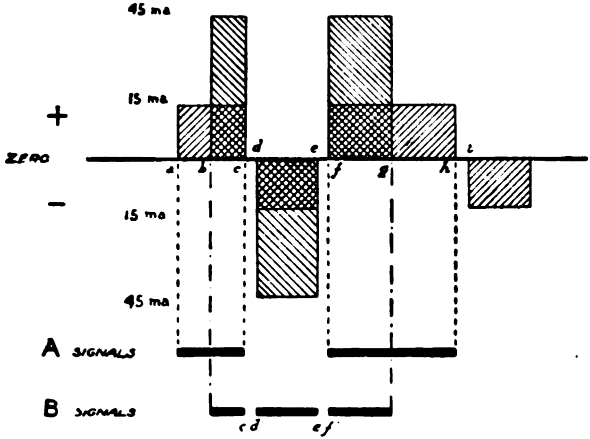


FIG. 152.—Interaction of keys on a quadruplex circuit.

But the current does not change in direction through the circuit instantaneously, and therefore the period of break extends from the time when the current falls to, say, 17 m.a. until zero is reached, and then again after the interval due to the key until the current has risen to 17 m.a. in the reverse direction.

Referring to Fig. 152, the conditions during the progress of the *B* mark from *d* to *g* are represented in skeleton by Fig. 153. The conditions with the *A* key at rest extend from *d* to *e*, and when depressed from *f* to *g*. With the *A* key at rest, and taking the values given in the table on page 292, the current through the line and line coil of the down relays is 40 m.a., whilst the current in the compensation coil is 10 m.a. If, now, the up *A* key be depressed the current in the line has to change to 20 m.a. in the reverse direction. When the line current has fallen to 10 m.a. the *B* relay will be entirely unmagnetized, since the compensation current is 10 m.a. in the reverse direction. It will therefore clearly be recognized that since a definite interval of time is taken for the current to fall to zero and to rise again in the reverse direction—a time which is increased by the time taken by the key to reverse the battery—that there is likewise a definite interval of break in the *B* signal.

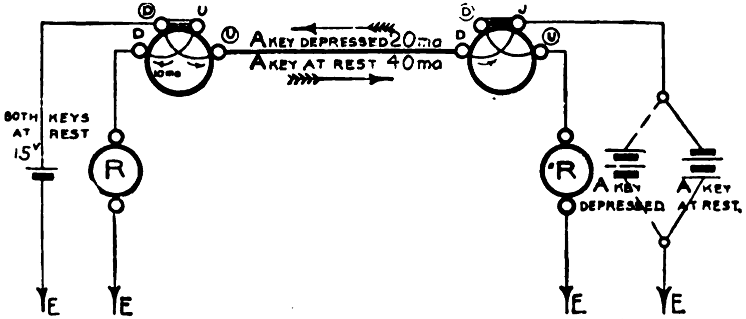


FIG. 153.—The "*B* kick."

THE CONDENSER *B* SIDE ARRANGEMENT.

The present standard device has been evolved from the suggestion of A. W. Martin to bridge over the interval of break by the action of a condenser placed across the terminals of the sounder on the *B* side. The device simplifies the adjustments and is capable of working over circuits of much higher *KR* than the uprighter device (limit $KR = 30{,}000$) which it replaced

A battery having an E.M.F. of 40^{v} (40 No. 1 cells) is connected in series with a 3-plug resistance box having a range of 100^{ω} to 700^{ω} by gradations of 100^{ω}, the *B* side 900^{ω} sounder and a 50^{ω} resistance coil to *S* (Fig. 154). A condenser which can be joined up to give a capacity of 2, 4, or 8 m.f. (Fig. 155) is placed across the sounder and variable resistance.

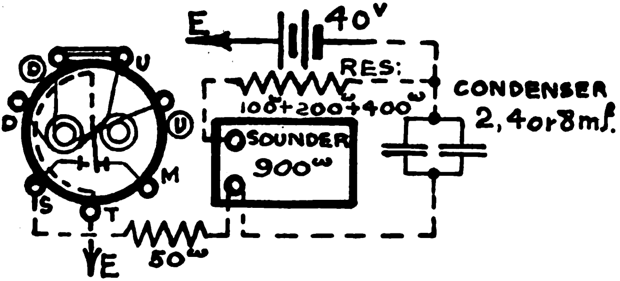


Fig. 154.—Standard arrangement of the "*B*" side.

The function of the 50^{ω} coil is to reduce the value of the current which would otherwise flow through the relay contacts at the moment at which the tongue makes contact with *S*. For whilst the condenser is being charged it acts as a path of negligible resistance, and therefore the current flowing through the relay contacts would, but for the interposition of the 50^{ω} coil, be so high as to produce electric welding of the contacts. This actually occurred in earlier arrangements, and it was to prevent it that the 50^{ω} coil was added.

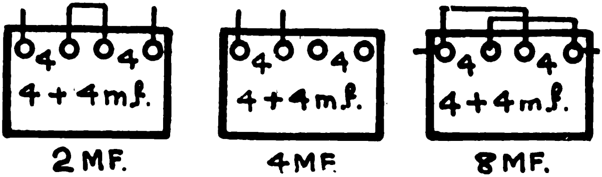


Fig. 155.—Methods of joining up the condenser.

When the tongue is held over to *S* by the *B* current, the condenser is charged as shown in Fig. 156 to a difference of potential which, but for the presence of the 50^{ω} coil, would be equal to and is only slightly less than the E.M.F. of the battery. If now the *A* key is also depressed, the spring of the relay breaks the local circuit until the current has risen in the reverse direction to a value sufficient to pull the tongue over to *S* again. When the current is broken at *S* the self-induction of the sounder causes an E.M.F. to be set up in such a direction as to tend to prolong the current, but in addition the condenser discharges through the sounder and resistance coils as indicated by the feathered arrow. The condenser discharge and the current due to the inductance of the sounder add together, and by their passage through the sounder prevent the magnetization of the cores of the sounder from falling sufficiently to release the armature before the current is re-established by *T* moving back again to *S*.

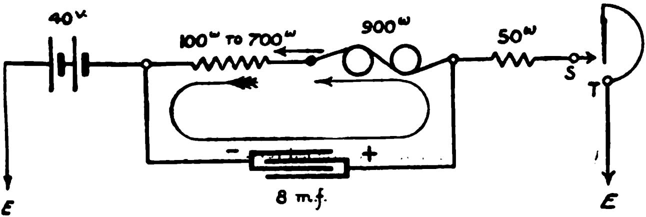


FIG. 156.—Action of condenser on "*B*" side local.

It may be interesting to remark that with a condenser joined directly across the terminals of a 900^{ω} sounder the conditions necessary for an oscillatory discharge are established (see page 239), and this is the chief reason for the use of the battery resistance coils $100^{\omega} + 200^{\omega} + 400^{\omega}$. Upon short circuits under 100 miles in length a 24^{v} battery only is used, and the resistance inserted in the battery resistance coils is given a much lower value.

THE "*A*" KEY.

This is a double current key with adjustable contacts, and it is adjusted so that it short-circuits the battery momentarily in moving up or down for the shortest possible interval of time.

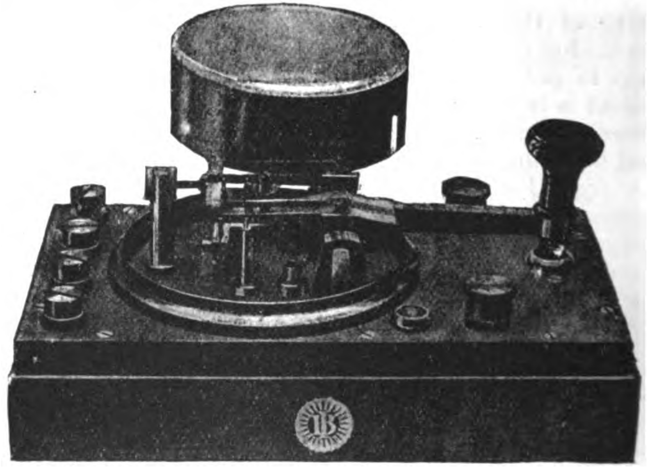


FIG. 157.—Six-terminal reversing key.

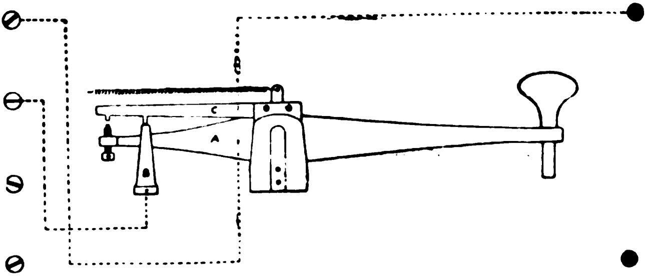


FIG. 158.—Principle of short-circuiting arrangement of reversing key.

THE "*B*" KEY.

For this purpose the right-hand half of a 6-terminal reversing key is employed. In the earlier types of key the divided lever was arranged in the same manner as a double current key with adjustable contacts, but the four contact springs were connected to four terminals at the top of the key whilst the divided lever was directly connected to the two lower terminals. In the latest form of key (Fig. 157) the arrangement is modified to arrange for a momentary short circuit. This will be apparent from Fig. 158, in which the arrangement of the right-hand half of the key is shown diagrammatically. The lever *A* in rising first makes contact with *C* and then raises it from *B*.

SPARKING, BATTERY, AND EARTHING, RESISTANCE COILS.

It has been shown that the battery is short-circuited by the keys when changing position, and in order to prevent the passage of an excessive current and sparking at the contacts of the *B* key when the *B* battery is short-circuited by the *B* key, a 50ω (marked *A*, Fig. 160) metal-cased resistance coil is placed in the lead of the *B* battery. This is termed the sparking resistance.

When the *B* key is at rest a resistance (marked *B*, Fig. 160) equal to the internal resistance of the *B* battery and its 50ω sparking coil is placed in the battery tap wire.

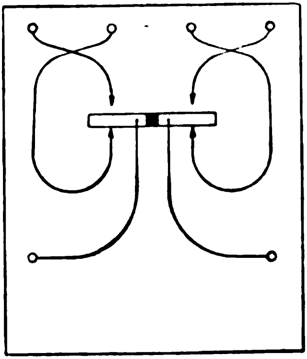


FIG. 159.—Connections of six-terminal reversing key.

The split wire is taken through a two-way switch so that the batteries and keys may be cut out and an earthing resistance (marked "Res." coil, Fig. 160) equal to that of the battery circuit (internal resistance of the whole battery + the 50ω spark coil) may be substituted. This provision facilitates the attainment of an accurate capacity balance.

EFFECTS OF SHORT-CIRCUIT IN THE INTERMEDIATE POSITION OF THE KEYS.

The effects of the momentary short-circuits by the keys

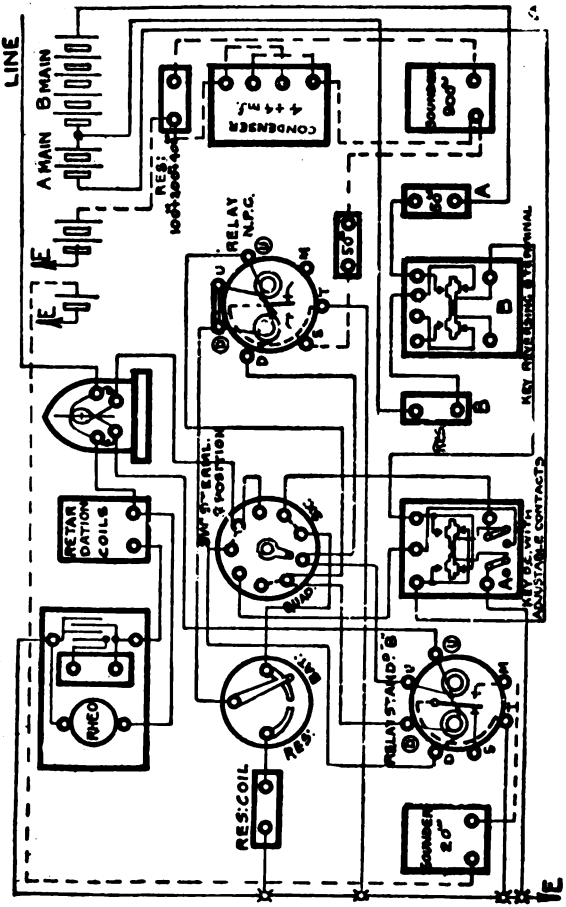


FIG. 160.—Quadruplex up station (individual or primary batteries.)

have no appreciable effect upon the distant balance. The battery resistance has the following values: (i) the normal resistance, viz. that of the full battery + the 50^{ω} spark coil, (ii) the resistance of the *A* battery + half the *B* battery and spark coil when the *B* key short-circuits, and (iii) nil, when the *A* key short-circuits. The conditions are only of momentary duration, and the battery resistance is not a large percentage of the total circuit resistance.

CONNECTIONS.

The full connections of an up station are shown in Fig. 160. The only point calling for comment is that a 9-terminal 2-position switch is added to provide for simplex working during slack periods, and thus to avoid the waste of energy due to the battery current flowing whilst the circuit is idle. Further, the circuit when simplexed can be concentrated. This switch when turned to simplex (Fig. 161) modifies the connections as indicated in Fig. 162, the rheostat being left in series with the *A* relay.

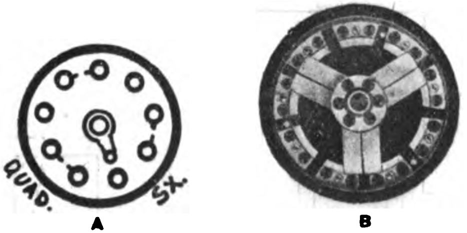


FIG. 161.—9-terminal-2-position switch. A. Connections at simplex; B. View of back of switch at duplex.

The quadruplex connections are comparable with those of the skeleton diagram given in Fig. 150, and the following points may be noted:—

1. The sending current splits at the *B* relay.
2. The up station normally connects negative to the split.
3. Under normal conditions the relays space due to the combination of the batteries (this settles the joining up of the line and compensation circuits).

4. The left side of the *A* key is earthed and the right side is connected to the split (may be deduced from 3).

5. At an up office *Z* and *C* of the *A* key are respectively joined to *Z* of the battery and the lower right terminal of the *B* key (*B* key determines whether the tap or full battery goes to the *A* key).

6. For a down office—

(i.) Reverse the connections of the two wires on upper terminals of the galvanometer

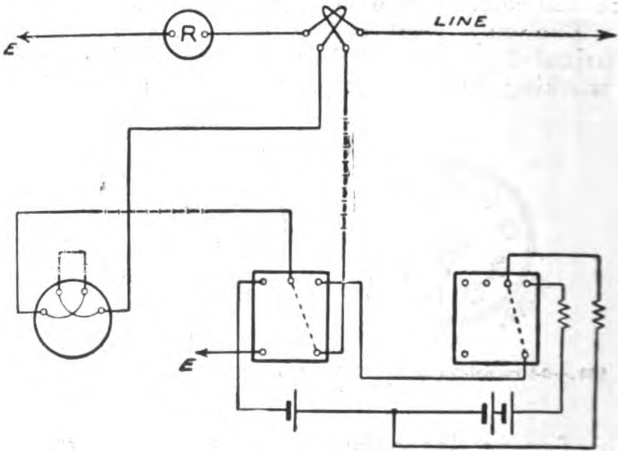


Fig. 162.—Connections when quadruplex switch turned to simplex.

(ii.) Reverse the connections of the two wires on the lower terminals of the galvanometer.

(iii.) Reverse the connections on *D* and *U*-circle of the polarized relay.

(iv.) Reverse the connections on *Z* and *C* of the key.

Balancing.

The balancing of the circuit is accomplished in the same way as in duplex working, but there are the distinct advantages of the larger power and the earthing switch.

Balancing should be effected with the full power (*i. e.* with the *B* key down), and the *A* key should be used in the same way as the double current key in duplex balancing. The distant earthing switch should be turned for capacity balancing, and the rules previously deduced (page 283) apply with equal truth to this operation.

ADJUSTMENT.

The adjustment of a quadruplex circuit is by no means a difficult matter, and the adjustments are reasonably permanent if carefully made. The whole of the trouble lies upon the *B* side, and it will be desirable to indicate a few obvious deductions from previous considerations. The *B* relay is worked by any current which attains a certain value greater than the *A* current. The best adjustment is therefore obtained when the *A* marks are just cleared off the *B* side. Assuming the values given in Fig. 153, it will be seen that if the *B* relay only marks when the effective current has attained 25 m.a. the effect of the *B* kick will be far larger than if it begins to work when the effective current has attained 17 m.a. If the relay works with the smaller current then the tongue is not released until the current has fallen from 30 to 17 m.a. instead of when it has fallen to 25 m.a., and it is again actuated when the current has risen to 17 m.a. instead of having to wait until it has increased by a further 8 m.a. The term "effective current" has been used to designate the difference between the values of the current in the two coils of the relays.

In clearing the marks off the *B* relay it is preferable to do this by removing the armatures further from the cores instead of by increased tension upon the spring. This adjustment can be made by moving the contact screws. The tension upon the spring should not be greater than is essential for reliability of action. The play of the tongue may be made as small as necessary.

The adjustment of the *A* relay and the sounders should call for no comment, as the matter has been fully considered previously. The reader is particular advised always to locate the point of defective regulation and to apply the remedy where the defect exists. A defect at one point may be partially rectified by defective regulation at a second one, but this process inevitably leads to unreliable adjustments.

It is essential that the ratio of the *A* and *B* currents shall be as one is to three, and that the powers employed at each end shall be approximately equal.

DECREMENT WORKING.

When the old uprighting sounder device was used on the *B* side, the arrangements were simplified by adopting decrement working, but this is no longer the case. Decrement working consists in arranging that the full battery shall normally be connected to the *A* key, and that the effect of depressing the *B* key shall be to reduce the current. This is readily effected by reversing the two wires on the top of the *B* key. With all the keys at rest the full power of the battery is in use, and both *B* relay tongues are held to *S* against the force of the spring. The *B* side sounder 20ʷ and local battery are then joined up between *T* and *M* of the *B* relay, and the play of the tongue of this relay is made as great as is consistent with the reception of clear, sharp signals. The *B* kick is then eliminated on short circuits, because with the *B* key at rest the depression of the *A* key only causes the tongue to kick towards *M*, and the current is re-established in the reverse direction before the local circuit can be affected.

This system has the disadvantage that full power is normally joined up, thus entailing a much greater expenditure of energy than the increment system, but, what is more serious, it imposes a greater strain on the insulation of the circuit, and wherever gutta-percha covered wire is used this is distinctly harmful. For very long lines the system is not possible, and there are, in fact, very many lines now working on the increment system which could not be worked at all on the decrement system.

USE OF QUADRUPLEX ON SHORT CIRCUITS.

Upon very short circuits such as those between a head office and an adjacent cricket ground or race course, it is necessary either to increase the resistance of the line by adding a rheostat or to place in the compensation circuit one coil of a standard relay and one coil of a non-polarized relay so as to balance the inductance of the distant apparatus.

OTHER QUADRUPLEX SYSTEMS.

The general principles of the Post Office system of quadruplex working have now been stated, but it will be obvious that the same object may be accomplished in different ways. The Bridge system of working could readily be adopted, but it must be confessed that although such an arrangement has been proposed it has rarely if ever been put into practice. Either this or the differential system may be worked by combination or by opposition, the former being the method adopted by the Post Office.

The quadruplex systems of America differ from our own chiefly in the arrangement of the non-polarized relay. In every case the keys are employed to complete local circuits, which work transmitters similar to those described in Chapter XIX. In many cases a third coil is wound upon the *B* relay, and so arranged as to accelerate the reversal of the magnetism of the relay.

It is interesting to note that on short circuits the condenser *B* side arrangement can be replaced by a polarized sounder and battery joined between *T* and *M* so arranged that normally a current flows through the completed local circuit in such a direction as to oppose the spring. Marks are therefore made by breakage of the local circuit when *T* moves over to *M*. The tongue of the relay should be given fairly wide play.

CURRENT REQUIRED AND TYPE OF BATTERY USED.

No. 1 cells are used upon ordinary, and No. 0 cells on very heavily worked quadruplex circuits, and the current required is from 10 to 15 m.a. upon the *A* side and from 30 to 45 for full power. The ratio of at least three to one should always be maintained. The two parts of the battery are often termed the *A* and *B* batteries, but it has been seen that the depression of the *B* key introduces the whole power, *i.e.* both *A* and *B* batteries.

The *A* side local is a 3-cell No. 1 Leclanché. On circuits under 100 miles in length the *B* side local consists of 24 No. 1 cells. On longer circuits 40 cells are used.

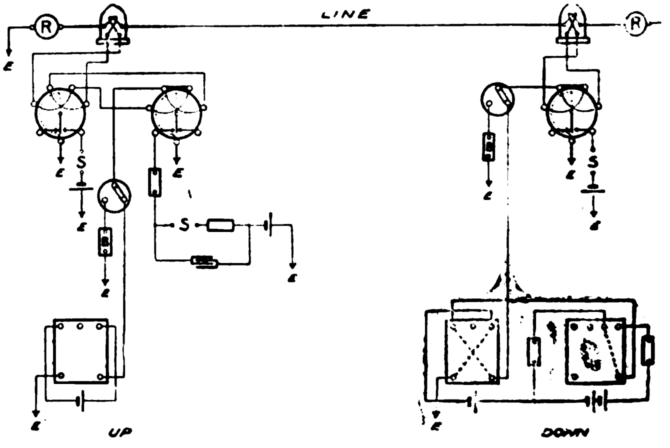


FIG. 163.—Full connections of a diplex circuit.

THE DIPLEX.

The diplex consists of a quadruplex at one end of which the *B* key and the major portion of battery power ordinarily required is omitted, and at the other the corresponding *B* relay is not needed. This arrangement provides for the simultaneous transmission of two messages in one direction and one in the opposite direction. At cricket grounds and other places where special arrangements are frequently made it often happens that practically the whole of the work consists in the transmission of messages *from* the special office. Where this is the case there is no advantage in providing two receiving paths at the special office; but one such path is, of course, essential for corrections and acknowledgments of messages transmitted.

The connections of such a circuit are shown in Fig. 163.

WHEATSTONE ON THE *A* SIDE.

A Wheatstone transmitter may be added and a receiver substituted for the *A* relay on a quadruplex circuit. The substitution of the receiver needs no comment. The connections required for the transmitter are fairly obvious, but attention may perhaps be drawn to the fact that the right-hand terminal of the *B* key is taken to the right-hand side of the two-way earthing switch, the lever of which is joined to *C* of the transmitter. The negative pole of the battery is teed to *Z* of the transmitter and to the other side of the earthing resistance, which latter is connected to the left side of the two-way switch. *MKZ*, *MKC*, and *K* are respectively connected to *Z*, *C* and the right terminal of the *A* key; *D* of the transmitter passes through the 9-terminal switch to the split of the relay. With the

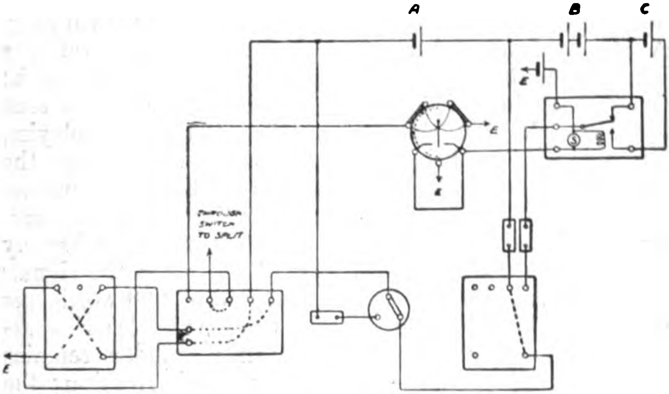


FIG. 164.—Quadruplex with incrementing voltages.

aid of these notes, the additions necessary to Fig. 160 should present no difficulty (Fig. 164 with the incrementing device eliminated gives the required connections). Motor-driven transmitters are to be preferred on quadruplex circuits for the reasons given on page 341.

The resistance of the contacts made at high speed by the transmitter are far higher than those of the double current key, with the result that the currents sent out when the *B* side key is depressed are seriously reduced in value. In order to obtain better results on long circuits, a device has been added which automatically increases the *B* voltage when the transmitter is running. A standard neutral relay with its coils in parallel is interpolated between U of the transmitter and earth: thus, when the transmitter is running, the currents sent out pass through this relay (Fig. 164). A relaying sounder and local battery are connected, so that the circuit is closed when the tongue of the relay makes contact with either *S* or *M*, thus pulling down the armature of the sounder and thereby adding the extra battery marked *C* to the *B* side battery. This helps the signals on the *B* side considerably, and a speed of 200 words per minute is obtainable even whilst the *B* side also is working. The armature of the relaying sounder remains down permanently whilst the transmitter is running; the principle involved in bridging the interval occupied by the tongue of the neutral relay in moving between *S* and *M* is, of course, identical with the automatic switch used on repeaters (page 636).

CHAPTER X

THE WHEATSTONE AUTOMATIC SYSTEM.

General.

THE generic term "automatic system" is usually employed to denote all the systems in which the signals are transmitted by mechanical means as opposed to those in which the signals are sent by a manually operated key. The speed at which most circuits can be worked by a machine transmitter greatly transcends the speed at which even the most highly expert telegraphist can operate a key. Moreover, the speed is constantly maintained and the marks are more accurately formed than would be possible with a key worked by hand.

The Wheatstone apparatus comprises three separate and distinct parts. Firstly, the perforator, which is employed to prepare the tape (or "slip" as it is termed) controlling the signals sent out. Secondly, the transmitter, which serves to send out signals in accordance with the perforations of the slip. Thirdly, the receiver, which is a very sensitive form of polarized direct writer.

In addition to this essentially Wheatstone instrument, a galvanometer, sounder, line and local batteries are, of course, required.

The Wheatstone system employed by the Post Office has maintained its supremacy over all other automatic systems since its inception, and even to-day its position is a very strong one. The objection to all automatic systems lies in the fact that a key clerk is required at each end to attend to the transmitter and receiver, and unless the operations of preparing the tape at the sending end and writing up or preparing the messages at the receiving end are more rapid than ordinary manual sending and receiving, then, given ample lines, a manual system is to be preferred. But, it is interesting to note that modern additions to the Wheatstone system have tended very largely to effect the staff economies suggested. In the first place, perforators operated by a keyboard similar to a typewriter enable an operator to perforate the tape for fifty to sixty ordinary commercial messages per hour, and as many as 100 messages have been dealt with in the hour. Then further economy has resulted by gumming the received morse slip on to specially prepared forms in all cases in which the message has to be re-transmitted, and in the case of messages to be delivered from the office at which they are received, by writing up the messages on typewriters. It is found that no difficulty nor extra delay is involved in transmitting messages from the slip gummed on to the special forms than in sending from a written form, and one operator can gum from 250 to 300 messages per hour.

Further improvements consist in driving the transmitters and receivers by electric motors, but the system so far described is purely and simply Wheatstone—indeed the Kotyra keyboard perforator is the original Wheatstone perforator operated by additional mechanism in the form of a keyboard.

A remarkable addition to the system has been invented by F. G. Creed, in which the Wheatstone receiver is replaced by the Creed receiving perforator. This apparatus produces at the receiving end a perforated slip identical with the perforated transmitting slip. This slip may be passed through transmitters, and thus automatically retransmit the messages without transcription, or the slip may be passed through a Creed printer which automatically typewrites the message upon suitable forms. A still further advance has been made by the invention, by H. Bille, of an electrically operated receiving perforator for which a working speed of 300 words per minute is claimed.

It will here be convenient to particularize the automatic systems which are regarded as competitors with the Wheatstone system. Firstly, there is the Murray automatic system in which (i) the transmitting tape is prepared by a keyboard perforator, (ii) the receiving apparatus delivers a perforated tape identical with the transmitting tape, and (iii) a printer which typewrites the message when the received tape is passed through it. This system on a long circuit gives a higher speed than the Wheatstone, owing to the use of the simplest possible alphabet, each letter of which consists of combinations of five consecutive currents without any interval of break.

There is also the new Siemens automatic system, which is capable of a speed of from 80 to 100 words per minute. The apparatus is remarkable for its simplicity and for the fact that the tape can be perforated at the receiving end from hand sending, and this tape can, with the aid of the transmitter, be used for retransmission.

THE WHEATSTONE PERFORATOR.

The perforator (Fig. 165), which is purely mechanical in its action, consists of five steel punches operated in suitable combination by the three keys, the slip being

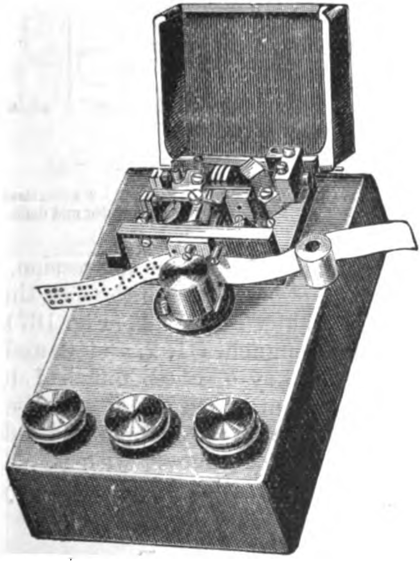


FIG. 165.—Wheatstone perforator.

automatically moved forward to the required extent immediately the key is released. The slip is from ·46 to ·48 inch wide, from 4 to 4½ mils in thickness, and is treated with olive oil in order to ensure cleanly perforated holes.

OPERATION OF THE PUNCHES.

The five punches occupy the relative positions shown in Fig. 166, and have been marked 1 to 5. Punches 2 and 4 are of smaller size than the other three and serve to form the central guiding holes. The middle key operates punch 2 only. This punch is attached to a small plate, and the extension of the middle key, upon depression, strikes the pin *b*, so forcing the punch through the slip, thus perforating a centre hole as shown under R_1 (Fig. 167). The left or dot key depresses punches 1, 2, and 3, and perforates as at R_2. The right key operates punch 1 by means of the extension plate and pin, 4 and 5 directly, whilst 2 is operated from 4. Punch 2 can be operated independently of 4, but when 4 is struck 2 moves with it. The perforations resulting from depression of the dash key are shown at R_3.

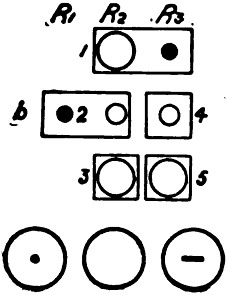


FIG. 166. —Arrangement of punches.

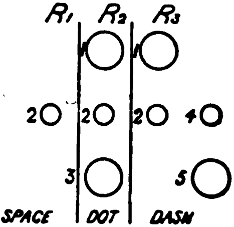


FIG. 167.—Perforations for space, dot and dash.

PAPER-FEEDING DEVICE.

The device for feeding the paper forward either one or two spaces as required may be seen in Fig. 168. The lever *K*, which has its axis upon the right, fits into notches cut in the underside of the levers R_1, R_2 and R_3, and is articulated with the crank *P* at *e*. Near the end of *P* is fixed a double-toothed pawl *E* engaging with the star wheel *S*. The drum-shaped wheel *W* is carried upon a light spring and holds the pawl in its normal position. The levers *K* and *P* are normally held in the positions shown in the figure by the action of the powerful spring

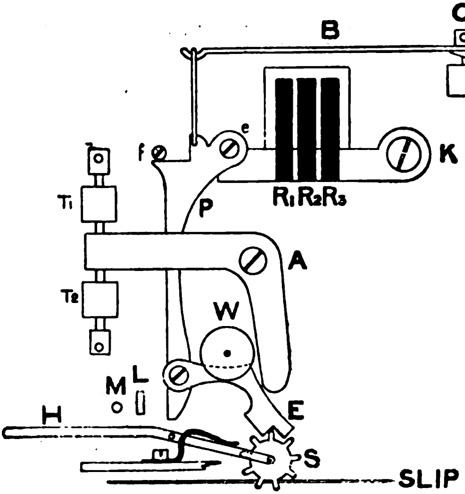


FIG. 168.—Part of perforator mechanism.

B, the tension upon which may be adjusted by the screws *C* and *D*.

When the centre key is depressed punch 2, actuated by R_1, passes through the slip and the levers *P* and *K* move forward (downward in the figure), thus carrying the click *E* to the left.

Immediately the key is released the spring *B* returns the levers to their normal positions and the click engages a tooth of the star wheel, thus moving it forward and bringing the paper into position for the next perforation. A similar result occurs when the left key is depressed and the paper is again moved forward by the requisite amount. The distance to which the front end of the lever *P* can be moved to the left is limited by the end of the lever *L*, but when the right key is depressed this stop is raised and *P* moves further to the left to *M*, with the result that the star wheel is moved round two teeth, as is obviously necessary. The lever *L* curves over the pawl and is pivoted upon the right. It is directly connected beyond the pivot to the lower side of the "dash" lever beneath the perforator base.

A consideration of Fig. 169, showing a vertical section through punches 1, 2 and 3, taken in conjunction with Figs. 166 and 167, will render the arrangement of the punches quite evident. The two spiral springs serve to return the punches (shown depressed) to their normal positions immediately the key is released. The ends of R_1, R_2 and R_3 are of sufficient depth to operate the three rows of punches.

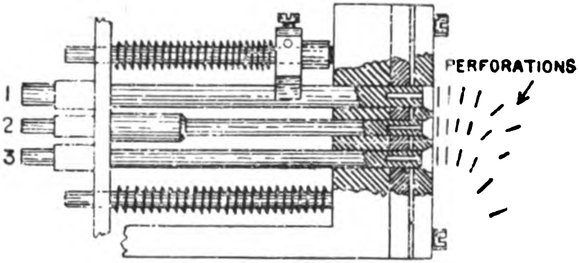


FIG. 169.—Perforator punches.

The star wheel *S* is carried by the lever *H* which serves to withdraw it when inserting the slip between the plates. The centre key is struck and the slip pulled gently forward until the star wheel engages with the centre holes.

Punches.

The solid punches formerly employed required frequent sharpening in consequence of their edges wearing away by the action of perforating the oiled paper. This was principally due to the fact that at each blow of the punch, a film of dried oil was deposited by the paper upon the surface of the punch which soon built up into convex form, the consequence being that the paper was bent over the punch before being perforated, and quickly wore away the cutting edge of the punch. Moreover, the perforations, being bent by this process, were sluggish in leaving the plates.

The new form of punch designed by J. W. Willmot has a hollow recess at its end, and therefore has no centre on which a deposit of oil can take place. As the annular surface of the punch remains flat a clean perforation is always made. It has a further advantage, *i. e.* that in coming into contact with the paper to be perforated a small amount of air is compressed in the recesses of the punches, which, after the perforation has been made, tends to blow away the punched-out portions of the paper, and also to prevent any oil or foreign matter accumulating in the recesses of the punches. The holes in the front plate through which the perforations are expelled have been chamfered, thus facilitating that process. When the punches require sharpening, the hollow or recessed punches are more easily ground, and a flatter surface obtained than is possible with solid punches, because firstly, having no centre there is less metal to grind away, and secondly, for the same reason they lie flatter upon the cutting surface of the oil-stone used for sharpening them.

AUXILIARY APPLIANCES.

The perforator is mounted upon a wooden stand provided with a drawer for receiving the perforations. Behind this is placed the box containing the roll of slip, and the second lid is raised to form a stand for the message or manuscript to be punched.

The keys of the perforator are operated with iron punching handles, the ends of which are recessed to receive the striking cushions of solid rubber. Two slips may be simultaneously perforated, and therefore double wound rolls of paper are also provided.

PERFORATOR ADJUSTMENT.

The adjustment of the perforator is a matter of considerable importance, and the bent lever *A*, with its adjusting-screws T_1 and T_2, is provided for this purpose. The lower extremity limits the distance at which the click engages the star wheel, and therefore the distance through which it is turned. The standard is 121 central perforations per foot, the distance being measured from the centre of the first to the centre of the 121st perforation. If the word "telegraph" is punched three times with the double spaces between the words the requisite number (121) is obtained between the first and last holes.

PNEUMATIC PERFORATORS.

In certain very large offices pneumatic perforators are

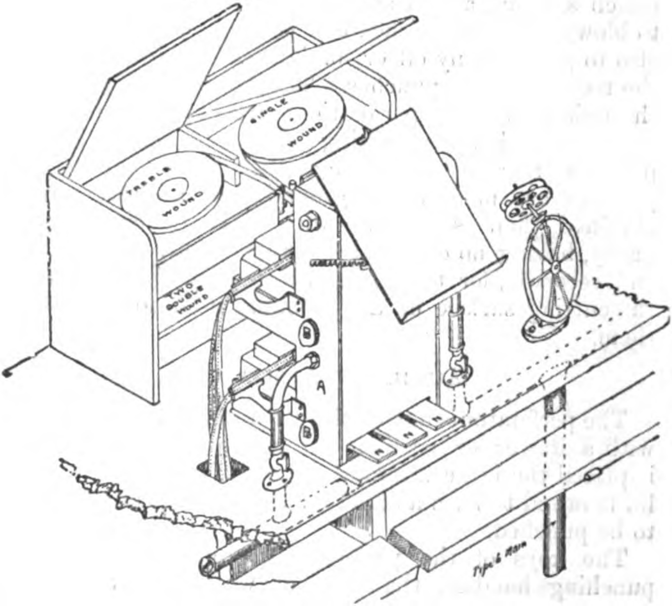


FIG. 170.—Appearance of a pneumatic perforator.

employed. In this way from one to eight slips can be simultaneously prepared. Four rolls of paper, one treble, one single and two double wound are provided, as indicated in Fig. 170. The two perforators are actuated by the three keys which are to be seen in the forefront of the figure. These keys operate valves (Fig. 171) which admit the compressed air, obtained from the pneumatic tube plant, into the piston chambers. Each perforator has an independent supply of air, and either or both may be worked at will.

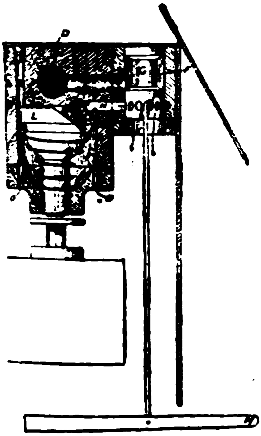


Fig. 171.—Pneumatic perforator valve and piston.

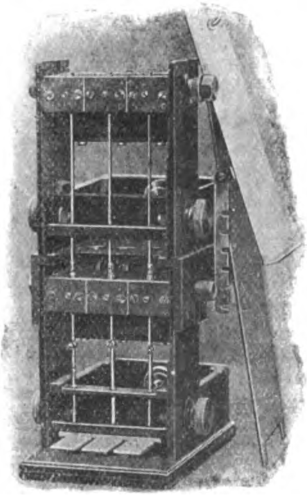


Fig. 172.—View of pneumatic perforator with front plate removed.

The sizes of the pistons are of course dimensioned so that the dot and dash keys which operate respectively three and four punches receive a heavier blow than the space key which operates only one punch.

The Gell Perforator.

The keyboard is similar to that of a standard typewriter, and the mechanism is so arranged that upon depressing a key the whole of the holes corresponding to the letter are perforated in the tape, and the slip is moved forward a distance equal to the number of feed holes in the letter, plus one additional to give the space between succeeding letters.

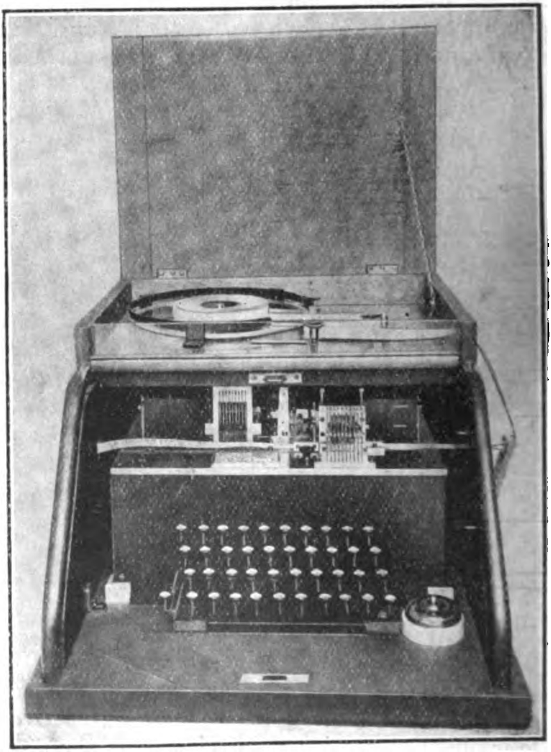


Fig. 173.—View of Gell perforator.

Fig. 173 gives a view of the instrument mounted on a felted slate base, with the roll-top cover, and the lid raised to show the tape wheel and automatic brake to prevent overcoiling.

Fig. 174 shows the instrument with the cover removed, and affords a general view of the instrument and of the action on the upper part of the main plate.

By removing the four corner screws the main top-plate can be raised from the frame by means of the two T-shaped handles. Fig. 175 gives the appearance of the underside, whilst Fig. 176 shows the inside of the frame.

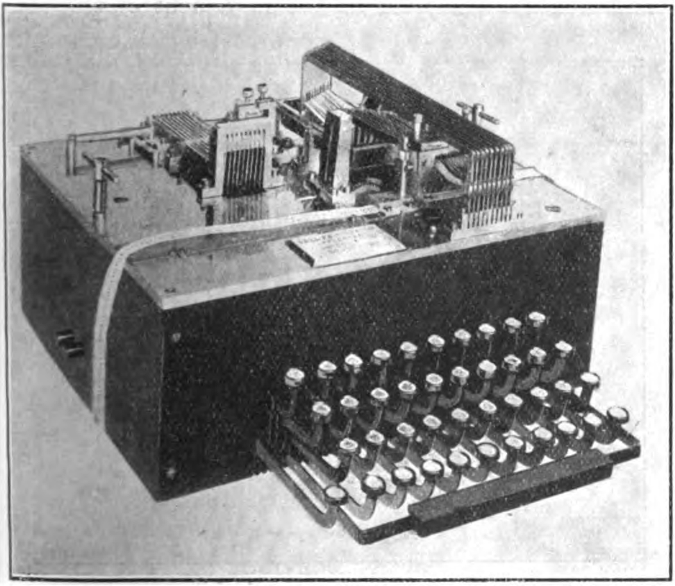


FIG. 174.—Gell perforator with cover removed.

Fig. 177 illustrates the die-plate, and Fig. 178 a section showing the punch action and slider. Fig. 179 shows the parallel bar action and a cross section of the letter combs, with one indicated as having raised a parallel bar.

The keyboard is modified from that of a typewriter by having the additional figures 1 and 0, three extra signs BT AR and /, and also RED for reduce feed and MAX for maximum feed. The key levers are pivoted on a differential fulcrum bar so that the working pressure on each key is the same.

Upon depressing a key the opposite end, faced with a hardened steel anvil, raises a T-shaped letter comb. This letter comb of hardened steel has on its upper surface certain projections according to the number and arrangement of the holes to be perforated to form the letter, and also a projection to regulate the movement of the tape corresponding to the length of letter perforated. These projections raise the parallel bars immediately above them, and by means of the associated mechanism cause the holes representing the required letter to be perforated, and the tape moved forward into position for the next letter.

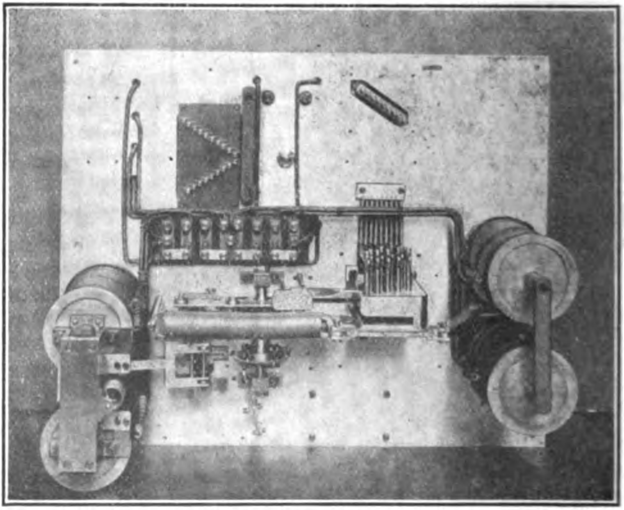


FIG. 175.—Gell perforator, underside of frame.

The parallel bars which are used as an intermediate action are twenty-nine in number; twenty are allotted to the formation of the letters as indicated in Fig. 177 and nine for the differential feed. The space hole marked

10, Fig. 177 also represents the parallel bar which controls the movement of the contact key. The parallel bars are spaced one-tenth of an inch from centre to centre, and the letter combs are milled out in the same ratio, leaving the projections where required. For example, letter comb

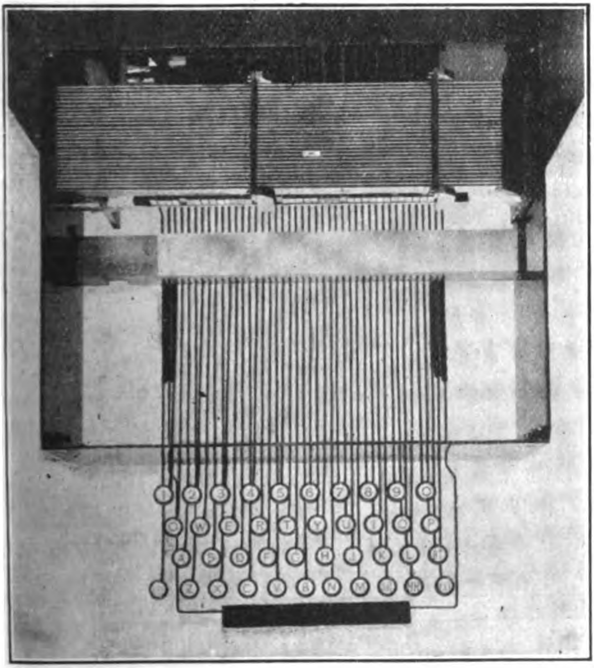


Fig. 176.—Gell perforator, inside of frame.

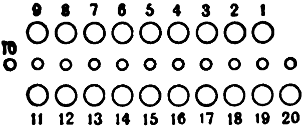


Fig. 177.—Gell perforator die-plate.

E has projections 9, 10, 11, and 29; letter A: 8, 9, 10, 11, 13, and 27.

The punches are carried in a slider which moves in a gunmetal frame, Fig. 178. In the sides of this U-shaped slider there are slots, and within these slots are the ends of the interlocking bars normally held so that the extremities are just within the inner face of the slider. In the slider are the marking and spacing punches placed with their slots opposite the ends of the interlocking bars, so that when an interlocking bar is moved towards the centre of the slider it engages with the punch, so that when the slider is moved downwards it carries the corresponding punch with it. The punches are carried between upper and lower guide plates, and immediately below the lower guide plate, and separated from it by two thicknesses of tape, is the cutting die-plate. The tape is carried between the lower guide and cutting die-

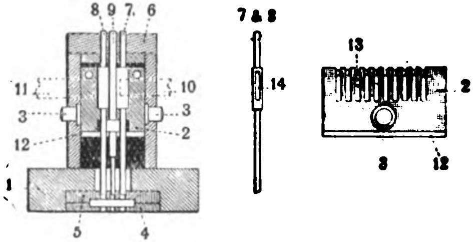


Fig. 178.—Gell perforator punches.

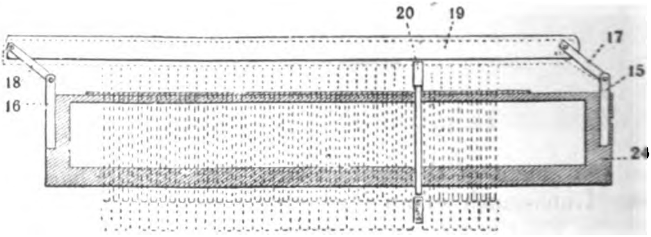


Fig. 179.—Gell perforator parallel bar and letter combs.

plate so that when the punch is forced downwards the tape is perforated.

The interlocking bars controlling the marking punches, at their ends remote from the slider, are connected to the upper legs of L-shaped levers; these levers, pivoted near their angles, have the lower ends, remote from the pivot, over pins which pass through the main plate. These pins are over their respective parallel bars. When a bar is raised it raises the pin which presses on the lever, and causes the interlocking bar to engage with the punch. In a somewhat similar manner the spacing punches are controlled, by means of reverse levers, and trackers, which draw in the interlocking bars from the opposite, or front side of the machine. These are shown in Figs. 173 and 174 in front of and over the top of the punches. The feed punches are rigidly fixed to the slider.

On each side of the slider there is a trunnion; connecting rods at their upper ends fit over these trunnions, and at their lower ends are connected to a pivoted lever. The opposite end of this lever is connected to the cross piece connecting the cores of a pair of sucking solenoids. When the solenoids are energized, the slider is moved downwards, and the interlocked punches perforate the tape.

At right angles to the direction of the tape and just to the left of the punch block there is a shaft which carries a star wheel, which engages with the feed holes in the tape, and also a pair of ratchet wheels with teeth reversed, and of the same number as the teeth on star feed wheel.

Beneath the shaft and in the same direction as the tape there is a skeleton bar pendant from the main plate on links at each end, and capable of movement from right to left and *vice versa*. Connected to this bar and straddling the feed ratchet wheels is a radial arm with an actuating pawl on the positive feed wheel. This radial arm is pivoted to the skeleton bar so that when the bar moves to the left the pawl moves over a certain number of teeth, and on the return of the bar the pawl forces the feed shaft round a distance corresponding to the number of teeth it originally passed over. The bar is moved to the left by a pair of sucking solenoids, and returns to its place of rest by the action of a spring as soon as the magnetism ceases in the solenoids.

The travel of the skeleton bar to the left is regulated by nine feed check pins which are interposed in its path. These pins are actuated by the previously mentioned projection on the letter comb actuating through levers.

When the oscillating skeleton bar is coming to rest under the influence of the spring there is a tendency under the longer feeds for the feed wheel to acquire momentum and overfeed; this is prevented by a lever working in unison with the oscillating bar, and interlocking with the reverse ratchet wheel at the end of the stroke. When the machine was speeded up to over 70 words per minute this lever tended to rebound and cause an overfeed. This has been prevented by a check click operated by the contact key.

The tape is held in engagement with the star feed wheel by means of a hinged shoe, which is raised by a key action when the tape is being inserted in the machine.

The star feed wheel is not rigidly fixed to the axle, but is carried on a flange and held in position by two capstan head screws. Elongated holes enable the star feed wheel to be rotated through a small arc so as to bring it in unison with the punches. When once in register the instrument remains so until it is taken to pieces.

The solenoids are controlled by a key which has two spring contacts, one for the feed and the other for the punches. The contact screws are so adjusted that the feed contact is made first and then the perforating, and on raising the key the circuits are opened in the reverse order. It is in this manner the successive necessary operations are obtained of predetermining the length of feed, setting the feed, perforating the tape, lifting the punches clear of the tape and feeding the tape.

The pins over the parallel bars controlling the feed limiting action are carried in a sliding piece capable of being moved to the right by the RED key, and of returning to rest under the influence of a spring. When the RED key is held down the parallel bar raises a pin, one to the right of the one nominally lifted, so that the feed is reduced by one hole, and letters perforated whilst the reduce feed key is held down run together. In this manner signals not on the keyboard may be formed, *e. g.* UD for note of interrogation, KK for brackets, and 55 for rub out. By this means the keyboard is kept as small as possible to facilitate touch typing; the three extra keys are used for frequently used signs, and all others are specially cut by two movements in place of one.

The MAX key perforates 11 holes, and feeds the tape forward that distance, and is used when a larger space is required instead of striking the space bar a number of times.

The mechanical efficiency is high, so that it responds freely to the fastest operator.

KLEINSCHMIDT KEYBOARD PERFORATOR.*

The keyboard (Fig. 180) is arranged in the usual manner with the extra telegraphic signs added, there being, in all, 41 keys and a space bar. A combination key is provided by means of which any two keys in the keyboard may be connected to form one character. The perforator resembles the Gell somewhat but differs in that one solenoid controls both the perforation, and feeding forward, of the tape.

The method adopted for the selection of the punches to be operated to form a character is illustrated in Fig. 181. Each character key lever KL is immediately over an intermediate notched lever IL.

Underneath each intermediate lever runs a number of tee levers suspended by a system of parallel links L. Only two of such levers and links are shown in Fig. 182, but there is a number corresponding to the number of punches in the gang. The punch controllers are attached to horizontal levers which are let into small slots in the side of the vertical portion of each tee lever. When the tee levers are depressed the punch controllers are raised and interposed between a punch hammer and the punch heads. The side elevation given in Fig. 182 makes this clear.

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* Abstracted from H. H. Harrison's paper, "The Story of the Keyboard Perforator," read before the London centre of the Institution of Post Office Electrical Engineers on 8th January, 1917.

In both the Gell and the Kleinschmidt perforators the work of selecting the punches is performed by depression of the key, whereas in some perforators this has been avoided, the finger touch being used only to originate the work of selection.

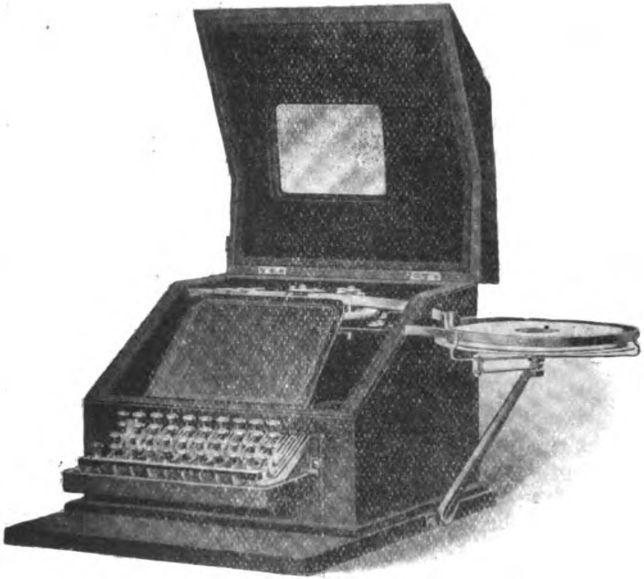

FIG. 180.—Kleinschmidt Keyboard Perforators.

The variable feed device, which remains to be considered, is of a very ingenious character. In any letter or character the last hole to be punched is in the bottom row and lugs are placed on the punch controllers to secure the correct feed. The stop on the last lower line punch operated on determines the feed, but as the device works from the right hand end of the punch gang, its movement will be smaller the longer the letter and *vice versâ*. Exactly the opposite of this is required, and an intermediate mechanism is necessary in order that the correct length of feed be effected. Fig. 183 shows how this has been accomplished.

PHL is a bell crank lever, pivoted to the frame, and rocked by a solenoid, not shown in the figure. It operates the punch hammer, also not shown, and in addition controls a feed operating lever *FOL* again pivoted to the frame. The lower end of the feed operating lever has pivoted to it a floating lever *FL*, the upper end of which will bank against the lug of the last punch selector forming a letter. The floating lever *FL* is connected to a link *L*, to a two armed intermediate lever *IL*, the upper end of which is joined by a link L_2 to the rotary arm carrying a feed pawl *P*.

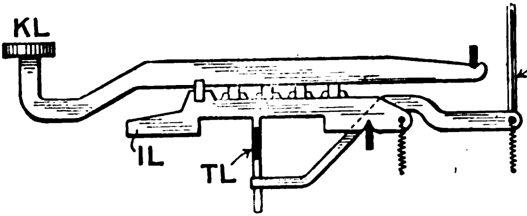

FIG. 181—Selection of punches.

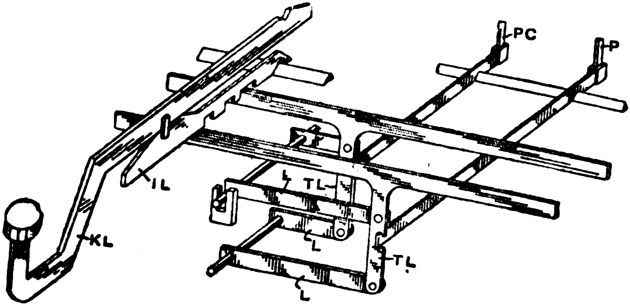

FIG. 182.—Selection of punches.

The action of the apparatus will readily be appreciated by considering the two skeleton diagrams at the bottom of Fig. 183, the left-hand diagram representing the feed for a long letter and the right-hand diagram for a short one.

When the solenoid is energized the punch hammer lever is rocked in a clock-wise direction, and it operates the feed lever by means of a lug on the latter entering a slot formed in the first-named lever. The rotary motion of the lower end of lever *FOL* continues until it comes up against stop *S*. In its motion it carries the floating lever *FOL* until this lever banks against the first lug at its head. Against this lug is a fulcrum, the floating lever *FL* rotates the intermediate lever *IL* in a clockwise direction, and the

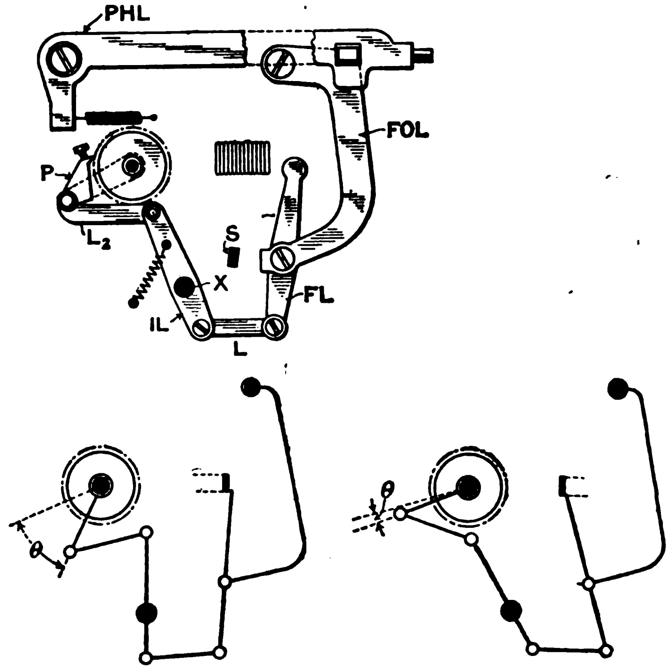

Fig. 183.—Paper feeding device.

feed pawl arm is thus drawn round in a counter-clockwise direction, setting the pawl for the subsequent feeding operation. The amount of rotation or angle depends upon the length of the letter, as shown in the diagrams. When the solenoid is de-energized, the floating lever flies back to a stop, not shown, and the feed wheel is operated under the combined effect of the spring on lever *IL* and the retracting effect of the feed mechanism linkwork.

It remains to explain the means by which the feed space between two letters is cut out to enable combination signs, such as *UD* and *SN*, to be formed. This is shown in Fig. 184. At the end of the feed stroke the pawl banks up against a limiting stop to prevent "over-throwing." A distance piece equal in thickness to the pitch of the feed ratchet wheel teeth is interposed between the limiting stop and the banking face of the pawl. Thus, though the pawl is rocked through an angle equal to the length of a letter plus one space, the space feed is only equal to that of the letter, the space element being cut out. The distance piece is operated by a key on the keyboard. The first letter key of a combination signal is first depressed, then the reduce feed key, and finally the second character key.

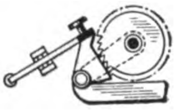

FIG. 184.—Feed.

TRANSMITTER.

THE DIVIDED LEVER.

The transmitter (Fig. 185) consists of a special form of double current key, the movements of which are determined by the positions of the larger holes in the perforated slip. This key consists of a divided lever playing between four contact points, and may conventionally be represented as in Figs. 186 and 187. The upper and lower halves of the lever are mechanically connected but are electrically separate, *i. e.* insulated from each other. The two positions of

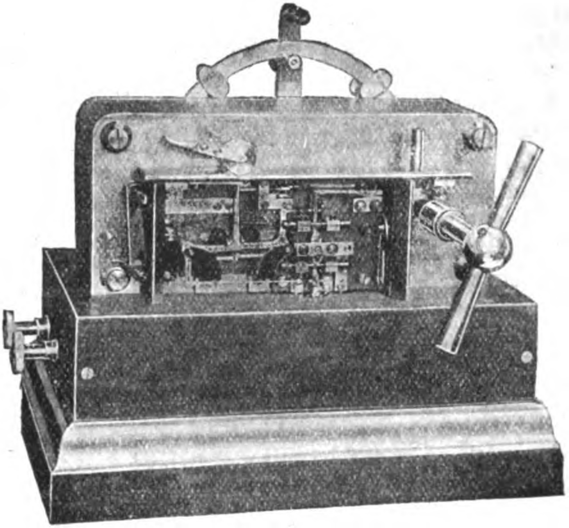

Fig. 185.—Wheatstone transmitter.

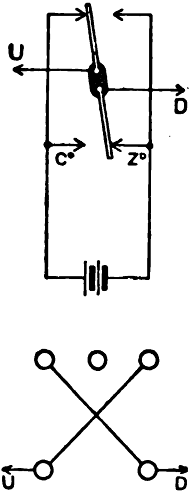

Fig. 186.—Divided lever in spacing position, and the corresponding connections of a double current key.

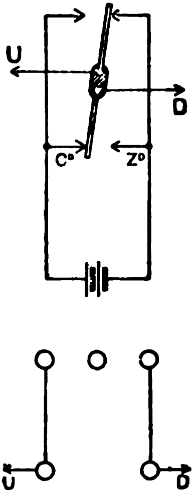

Fig. 187.—Divided lever in marking position, and the corresponding connections of a double current key.

the lever are shown side by side with the corresponding positions of a double current key below them. The upper half of the lever is connected to the up line and the lower half to the down line, and the battery contacts have been marked to show the connections which result when the lever rests against them. It will be seen that the deflection of the lever (top) to the left makes the same connections as a double current key at rest but with its switch to send. The actual arrangement of the divided lever is shown upon the right in Fig. 188. The battery contacts correspond strictly with the positions shown in the previous figure, and the upper and lower halves of the lever are distinctively marked. The upper part terminating under *J* is purely mechanical in function.

It now remains to explain the mechanism by which the perforated slip controls the position of the divided lever.

MOTIVE POWER.

The mechanical power required to drive the transmitter mechanism is usually furnished by the gradual descent of a heavy weight acting through a train of wheels. A key for periodically raising the weight, and a governor, operated through a variable speed gear, form part of the arrangement. The descent of the weight causes the rocking beam to move up and down at a speed which conforms with the rate at which the star wheel moves the perforated slip through the instrument. These two allied movements are made by suitable gearing. The rocking beam is furnished with two pins P and P_1 (Fig. 188) which project horizontally and oscillate with it. The movement of the beam is effected by a horizontally projecting pin placed near the edge of the revolving wheel and connected by a lever to one end of the rocking beam. The revolution of this driving wheel causes the beam to rock up and down upon its central pivot.

ARRANGEMENT OF THE RECIPROCATING RODS AND DIVIDED LEVER.

The two pivoted cranks A and A' are held against the lower side of P and P' by the two spiral springs connected at right angles to the lower extensions of *A* and *A'*. Rising from the ends of the two cranks are the pivoted rods *S* and *M*. The rod *S* in Fig. 188 stands outwards from the page in front of *M*, and *M* has a slight forward lead in advance of *S* in the line of the perforated slip. These positions have been modified in the figure in order that both rods might be distinctly shown. The play of the rods in a direction to the right is limited by two adjustable screws against which they are normally held by the two spiral springs fixed to them and to the pin on the right. The rods pass through two slots in the brass case (shown in Fig. 185) of sufficient width readily to admit them, but without permitting any considerable movement in a direction transverse to the motion of the slip past them. Between the rods is placed the star wheel, the projections of which pass through the central holes of the perforated slip, so guiding and propelling it. Above the star wheel is placed a wheel rather broader than the slip and with grooves which engage the projections of the star wheel as they pass through the slip. This wheel is furnished with a handle, so that the slip may readily be removed without having to wait until the whole length has passed through the transmitter.

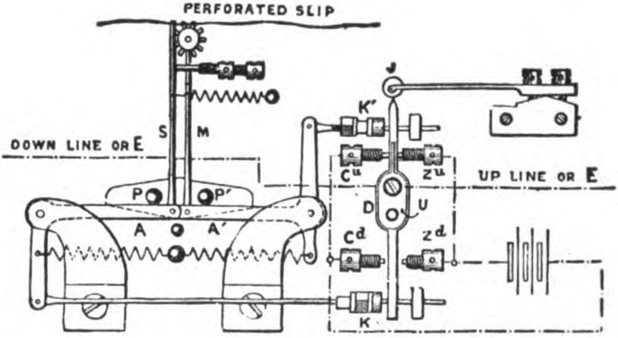

FIG. 188.—Principle of Wheatstone transmitter.

With no slip in the transmitter the rods *S* and *M* follow the motions of the rocking beam, and so alternately rise and fall with it. The lower end of the left crank moves to the right when the rod *S* rises, and this pushes the lower end of the divided lever over to the right by means of the rod and boss ***K***. The rising of the back rod ***M*** similarly causes *K′* to move the top end of the divided lever to the right. Examining the last two sentences with the aid of Figs. 186 and 187 will show that a spacing current is sent out when the front rod *S* rises, whilst a marking current results from the rising of ***M***. The effect of running the transmitter without slip is to send out an unbroken series of reversals which register dots upon the distant polarized receiving instrument.

If, after the marking rod has risen, the spacing rod is stopped at the level of the paper, the marking current will be continued until the spacing rod is able to rise. The marking rod in rising moves the divided lever over to the right (upper part to the right, lower to the left), and it is held firmly against the contacts by the jockey wheel *J*. The lever never permanently occupies the central position shown in Fig. 188, but this method of drawing shows clearly the correct relative positions of the jockey wheel and the upper extension of the divided lever. This extension is mechanical and is electrically separate from the upper half (up line terminal) of the lever. It will be seen that immediately the lever moves to either side of the centre of the jockey wheel the spring which carries the wheel ensures that the contacts shall be firmly made and maintained.

ACTION OF TRANSMITTER IN SIGNALLING A WORD.

A sketch of the perforated slip required to transmit the word "and" is shown in Fig. 189. The upper holes pass the rod ***M***, and the lower ones pass *S*. When in the transmitter the lower holes are to the front of the transmitter, and the slip moves past the rods from right to left. The exact process by which the punched holes in the slip control the positions of the lever may now be very readily traced. Let the perforated slip depicted in Fig. 189 be passed through the transmitter, and let it be assumed that prior to this the *S* rod last rose above the level of the paper. This being so, the lever was pushed over to the left (lower portion to the right), and is held there by the jockey wheel and spring. The central holes of the slip engage the star wheel, and the slip is drawn forward. The marking rod rises with the upward movement of P' (Fig. 188), but meets the full paper which prevents it rising sufficiently to cause K' to touch and push over the divided lever. The spacing current therefore continues. The spacing rod next rises when P moves upwards, but, meeting the full paper, it does not cause K to touch the lever. The rod M on rising again is still met by the paper, and is therefore unable to stop the spacing current which still continues. The spacing rod next rises, but is met by the paper. The first holes are now opposite the rods, and when the marking rod rises it passes through the hole and reverses the position of the divided lever, thus sending out a marking current. The spacing rod upon rising passes through the hole opposite that through which the marking rod has just passed. This returns the lever to the spacing side, and ends the mark by restoring the spacing current. Where the two rods successively pass through two holes directly opposite each other the shortest marking current, a dot, is transmitted. The marking rod now rises through the hole opposite 5, and a marking current again results. The spacing rod, however, is met by the full paper, and is therefore unable to reverse the lever, with the result that the jockey wheel still holds the lever to the marking side. The marking rod next rises opposite 6, but meeting the full paper leaves matters *in statu quo*. The spacing rod now meets a hole, and upon rising through it, withdraws the mark by reversing the lever. At 7 the marking rod is unable to rise

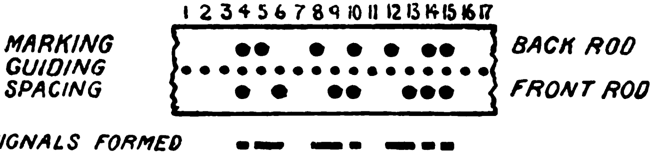

FIG. 189.—Perforated slip and corresponding received marks.

fully, and the space continues until it again rises at 8. The mark then commenced is not ended until the spacing rod has risen for the second time, when it passes through the hole and ends the dash at 9. At 10 a dot is transmitted, and the spacing current again continues until 12 is reached, when the dash in "d" is transmitted, followed by the two dots. The last current is of course spacing.

In commencing the detailed explanation of the transmission of the word "and" it was assumed for convenience that the divided lever was on the spacing side. This assumption is not warranted, since it may readily happen that in putting in the slip *M* was the last rod to rise above the level of the paper. The effect would be that a continuous mark would be registered until the spacing rod rose at 4. In perforating a slip for transmission a few A's are usually punched before the actual message, in order that the first signal of the message may be clearly received and may not be merged into a continuous mark.

SUMMARY OF ACTION OF TRANSMITTER.

The results of the previous investigations into the action of the transmitter may now be summarized—

1. The back rod and back holes control the marking, and the front rod and front holes the spacing currents.
2. The last rod to rise above the level of the paper produces an effect (spacing or marking) which is continued until the other rod rises above the level of the paper.

MAGNETIC BIAS TRANSMITTER.

In another pattern of transmitter the jockey wheel has been replaced by a magnetic bias. The arrangement is depicted in Fig. 190, where it will be seen that the upper part of the lever plays between the polepieces of a powerful horseshoe magnet. The device is so entirely similar in action to a relay which has been adjusted to neutrality that detailed description is scarcely necessary. Suffice it to say that when deflected to either side the extension of the divided lever is nearer to the polepiece against which it deflects, and that magnetic attraction serves to maintain the contacts made by the movement of the lever. The advantages gained are (1) the entire elimination of the heavy downward pressure due to the use of the jockey wheel and spring, and (2) the lever is held over more firmly, (3) it requires a smaller relative movement between the magnet and the divided lever than was necessary with the jockey wheel, and (4) it requires less power to drive.

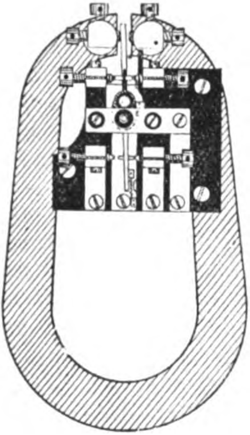

FIG. 190.—Magnetic bias transmitter.

Whilst effecting this change an opportunity was taken to substitute pivoted crossheads for the holes and pins of the horizontal levers, and also to make their adjustments more easily accessible. These improvements, due to J. W. Willmot, have had a marked effect in two directions; firstly, greater permanency of adjustments; and, secondly, far less wear and tear of the moving parts. The former is a matter of the utmost importance for the reason that the adjustment of a transmitter is at the best a lengthy and tedious operation, and when traffic is being delayed by such a fault it is quite hopeless to attempt to remedy it on the spot. In such cases a new transmitter should be substituted at once.

TRANSMITTER BIAS.

The four battery contact screws require most careful and accurate adjustment in order that the currents sent out by the transmitter may be of exactly equal duration. The positions of K and K^1 (Fig. 188) are, for the same reason, of equal importance. When once made, re-regulation is not required for some time, but it is inevitable that sooner or later the relative positions of the moving parts will slightly alter. The result in a pronounced case is that the transmitter sends out a current in one direction only when run without slip. In less pronounced cases the defect is termed a marking or spacing bias, according to whether the marking or spacing current is of longer duration than the other. If the currents are, as they should be, of exactly equal duration and value the needle of the galvanometer will oscillate to an equal extent upon either side of zero. If the galvanometer is permanently deflected it is evidence that a bias exists, or, in other words, that the marking and spacing currents are of unequal length. Therefore, to prove a transmitter it should be run very slowly without slip, and the value of the deflections upon the galvanometer in both directions should be quite equal. The speed should then be increased, when the galvanometer should stand at zero, or rather should oscillate to an extremely small extent about zero.

ARRANGEMENT FOR REGULATING THE SPEED OF THE TRANSMITTER.

It is essential that the speed of the transmitter should be capable of wide variation in order that the same instrument may be used upon all Wheatstone circuits, and also to meet the case where a reduction in speed is necessitated by slight defects upon the circuit. This is effected by the governor and the variable speed gear shown in Fig. 191. The smaller german silver disc *V* serves to transmit the motion of the steel driving disc *G* to the steel fan disc *N*. Now the position of *V* between *G* and *N* may be altered by means of the speed lever. In Fig. 191 the fan disc *N* revolves much faster than the driving disc, and therefore a comparatively slow motion of *G* produces a relatively fast motion of *N*. When the disc *V* is moved to the position shown in Fig. 192, the conditions are reversed and a fast motion of the driving disc produces a relatively slow motion of the fan disc.

The two fans are mounted upon toothed wheels engaging with the wheel upon the axle of the fan. Normally the fans are held in the position shown in Fig. 193 by the action of the spring which is clearly visible in Figs. 191 and 192. Immediately the fan disc begins to move the fans fly outwards (see Fig. 191) by centrifugal force, and offer a resistance to passage through the air which becomes greater and greater as the area of the circle described by the outer edge of the fans increases. It will therefore be seen that when the connecting disc *V* is in the position shown in Fig. 191, the speed of the transmitter is least on account of the energy taken to drive the fan. In the following figure the conditions are reversed, and the energy taken up by the fan is correspondingly less since a fast motion of *G* produces a relatively slow motion of *N*.

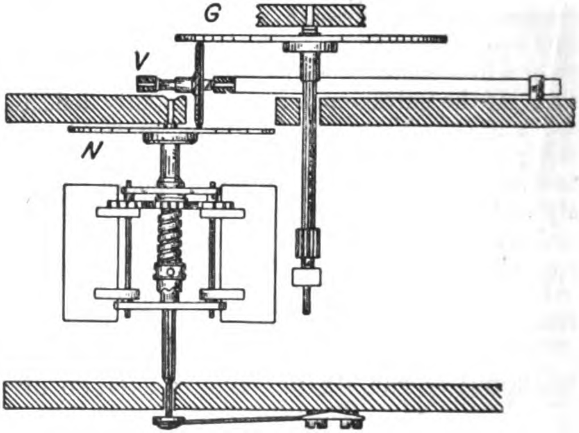

FIG. 191.—Arrangement of speed gear and fans—Lever at "Slow."

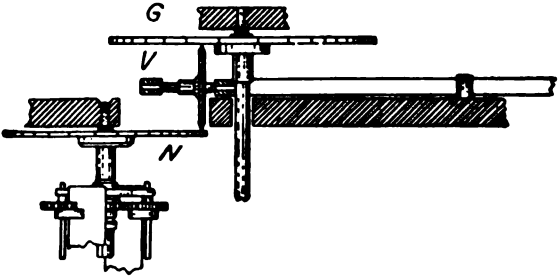

FIG. 192.—Lever at "Fast."

Since the friction between the three discs is relied upon to transmit the motion of the driving system to the fan governor, it is essential that the discs should be firmly pressed together, that the surfaces which are brought into contact should be perfectly smooth, and, lastly, that the discs should be absolutely clean. The spring (Fig. 191) acting on the axle of the fan holds the fan disc in firm contact with the movable disc. A jewelled bearing is employed, as the wear upon the pivot would otherwise be very great.

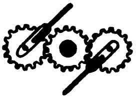

Fig. 193.
Fans closed.

ACTION OF FAN IN MAINTAINING UNIFORMITY OF SPEED.

The fan governor also performs another important function in eliminating all minor fluctuations of speed. If, whilst the instrument is running, there suddenly occurs a tendency towards reduced speed the fans move inwards a little, thus taking less energy to drive them, and so reducing the effect. In similar fashion the governor opposes any sudden increase of speed.

STOPPING AND STARTING LEVER.

A lever is provided to stop and start the transmitter. This lever when in its left-hand position (transmitter stopped) engages with a projection upon the axle of the fans. When turned to the right the fan axle is released and the instrument at once starts. In addition, the lever actuates a switch placed upon the under-side of the instrument. This switch is described and explained upon page 356, under the heading of "Transmitter Switch."

"BOLTING" OF TRANSMITTER.

If by any chance a little grease or oil should get on the discs or should the spring become weak the transmitter will "bolt." The whole of the mechanism which is driven by the weight is released from the control of the governor, the speed becomes abnormally great, and the weight rapidly descends. This descent is in fact so rapid that injury would result if the foot were caught by the falling weight, and therefore an iron guard is always placed round the weight in such a way as to prevent the feet from being placed beneath the weight.

SPEED OF SLIP.

The transmitter should give a slow speed of not more than 7 feet and a high or full speed of not less than 80 feet of slip (400 words) per minute. The speed of working may be obtained by dividing 3000 by the time in seconds occupied in passing 10 feet of perforated slip through the instrument. As the base of the receiver is exactly 12 inches long it may be used as a measure.

VYLE AND SMART MOTOR-DRIVEN TRANSMITTER.*

The advantages gained by substituting electric for weight driving are to avoid the necessity for winding up the weight to dispense with weight guards and the large holes cut in the instrument tables to receive the chains. Also

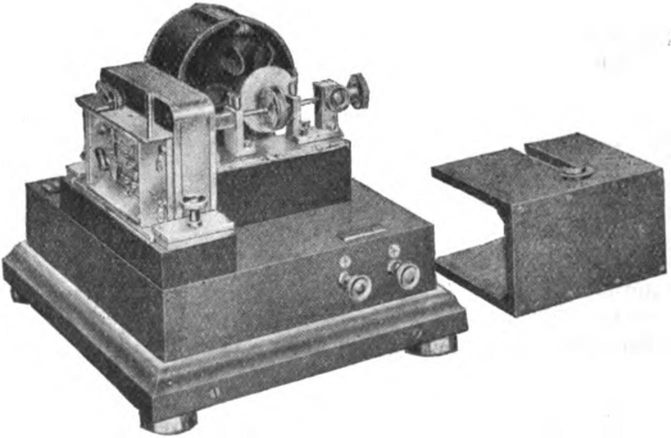

FIG. 194.—Vyle and Smart motor-driven transmitter.

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* Extracted from an article entitled "The Motor-Driven Wheatstone Transmitter," by C. C. Vyle and E. V. Smart, in *The Post Office Electrical Engineers' Journal*, Vol. I. pp. 97–102.

it provides greater rapidity in attaining full speed on starting. The abolition of weight driving facilitates the work of the key clerk, and eliminates the delays and corrections due either to the transmitter running down or to the sudden and irregularly increased speed due to overwinding. Owing to the comparatively slow speed at which an ordinary transmitter arrives at its proper speed there are long intervals of disconnection during this interval, and on quadruplex circuits the *B* signals are seriously interfered with, hence the superiority of motor-driven transmitters on such circuits.

The motor is series wound to secure rapid rise to full speed, and it will develop $\frac{1}{16}$ horse-power when connected to a 110^{v} supply. An extension of its axle carries a thick circular German silver plate suitably backed up to obtain rigidity. On the front of this plate there rests the edge of a friction disc, consisting of two thicknesses of compressed hide held tightly between two metal plates of slightly less diameter. Sufficient pressure between the motor driving plate and the disc which it drives is obtained by the two spiral springs attached to the opposite side of the shell of the motor and bearing on the projecting axle, friction being reduced by the interposition of a ball-bearing. This pressure is further increased by slightly displacing the motor armature so that when running it also tends to push the driving plate on to the disc. The principle involved in obtaining variation in speed according to the relative positions of two discs at right angles to each other has already been considered, but one interesting feature may be pointed out. It will be observed that the speed screw merely pushes the axle of the driven disc outwards to increase the speed, and that no special provision is made to move the disc from the fast to the slow position. The reason for this lies in the fact that the disc, if free to do so, moves towards the centre of the driving plate when the conditions are as indicated in Fig. 194.

The axle of the transmitter terminates in a barrel, most of the internal train of wheels necessary for weight driving being eliminated. This barrel is grooved or toothed so that the wheel on the axle of the raw hide disc engages with it at any point along its length determined by the position of the disc.

A dust-proof switch is used to start the instrument. This switch operating a bell-crank lever connects the power leads to the motor, as well as performing the functions of the electrical portion of the ordinary transmitter switch.

The transmitter portion can be changed in a few seconds, all the electrical connections being made by buffer contacts.

It may be remarked that there is also a Mulligan direct motor-driven transmitter on the same principle as the receiver described later.

THE RECEIVER.

The receiver is a polarized direct writer of somewhat special construction. Its electrical and magnetic parts are almost identical with those of the standard relay. Between its two electromagnets are placed two soft iron armatures rendered magnetic by induction from a powerful horseshoe magnet placed behind them. There is, however, the difference that the spacing screw moves the electromagnets bodily to right or left according to the direction in which the screw is turned. In a relay the contact points are mounted upon a movable platform, whilst in the receiver they are fixed.

Since there is no necessity to limit the space taken up by this magnet it is not curved round the coils. The upper end of the axle carrying the armatures bears an arm through which passes the revolving ink wheel axle (Fig. 195). The movements of the armatures produce a lateral movement of the ink wheel, so bringing it into contact with the slip and thus making a mark. The standard breadth of the marks is 16 mils.

INKING ARRANGEMENTS.

The armatures normally rest upon the right side, and a current in the direction *U* to *D* causes them to be deflected to the left. The small inking wheel (Fig. 195) revolves in a direction opposite to that in which the slip (3½ mils thick) is carried past it, and it is kept inked by the larger feeding wheel which dips into the ink-well. This wheel revolves in the opposite direction to the inking wheel, and is normally all but touching it. The object of the device is to prevent large quantities of ink being thrown on to the paper when the speed is varied, and the use of the intermediary wheel ensures that the inking wheel shall always be sufficiently inked, but at the highest speed shall not be inked to such an extent as to cause the marks to be indistinct. In fact, so well does the arrangement fulfil its function that there is no practical difference in the marks between slow and full speed.

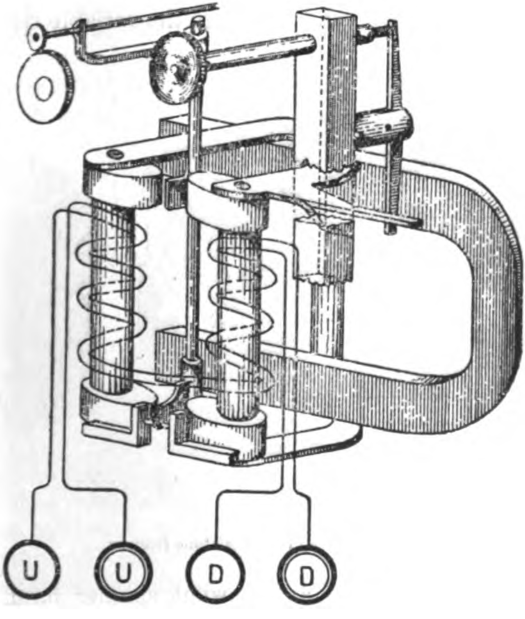

Fig. 195.—Principle of Wheatstone receiver.

MOTIVE POWER.

As in the case of the transmitter, the power is supplied by a weight geared to a train of wheels. The speed is adjustable by means of the lever at the back which alters the position of the german silver driving disc upon the fan disc in a similar manner to that described in the case of the transmitter. The speed of the star wheel in a Wheatstone transmitter is much higher than that of the paper roller in the receiver, and therefore the variable speed gear in the latter case is of a somewhat simpler form. The german silver disc is carried upon an axle which is directly geared to the driving axle by means of toothed wheels, and there is thus only one connection produced by friction. The governor used to regulate the speed, and the starting and stopping device are also similar to those used in the transmitter.

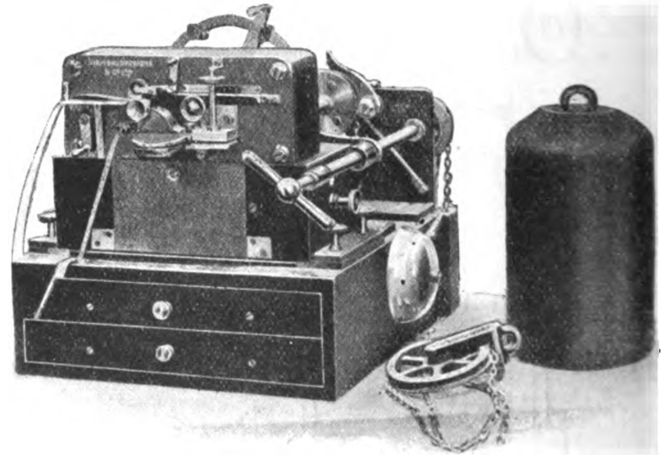

FIG. 186.—View of a Wheatstone receiver.

The descent of the weight causes the slip roller and the inking and feeding discs to revolve. Above the slip roller is placed a second roller which may be raised by moving the small front lever at the top of the instrument to the right. This facilitates the removal of the paper dust which accumulates round these parts of the receiver. The general appearance of a Wheatstone receiver is shown in Fig. 196.

DOUBLE SLIP DRAWER AND BELL.

Receivers are frequently furnished with two slip drawers (see Fig. 196) so that the slip from the second drawer may be rapidly brought into use in the event of that in the first drawer running out. This can be done so rapidly that the interval between the insertion of two consecutive punched slips is ample for the purpose. It is also now the custom to redden a length of the slip near the end of the roll so as to give timely warning of its coming exhaustion.

A short chain is attached to the weight in such a way that when the weight is nearly run down a bell is rung, thus warning the key clerk that it should be re-wound.

MOTOR AND TRAIN.

The receiver consists of two separate parts, the motor and the train. The former comprises the slip drawers and, as its name implies, the weight and winding and driving axles. By means of a catch at the back, the driving axle, which is furnished with a ratchet wheel, can be held by moving over the pawl seen to the right of the front chain wheel. The train can then readily be removed from the motor and another substituted. This is obviously a much more expeditious process than removing the instrument as a whole.

WINDING OF COILS.

The windings of the coils and their terminals are shown in Fig. 197. The use of a single winding of correspondingly thicker wire, instead of the two windings placed in parallel, would give a slightly better figure of merit. Upon the other hand the arrangement described no doubt facilitates differential adjustment.

ADJUSTMENT.

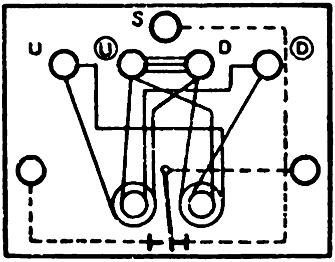

FIG. 197.—Connections of receiver.

The lower armature is furnished with a platinum-tipped extension for completing the local circuit of the sounder. The adjustment of the instrument is fortunately quite simple, but it must be remembered that two conditions have to be fulfilled, viz. that both the printing and the sounder marks should be correctly received. By improper adjustment it frequently happens that only one of these conditions is fulfilled. The inking discs should be kept clean, since more play is required and a slower speed of working otherwise results. The best method of adjustment is as follows:—

1. Place the spacing screw in its central position.
2. Adjust the left contact screw until, when the tongue is put over to the left, a broken line of dots appears upon the slip, continue this until the point is reached where a full line is just obtained, and give a further slight turn to the screw in order to provide a margin.
3. Close up the right contact screw until the continuous line is just cleared when the tongue is moved to the right. Then give a further slight turn to the screw to provide a margin.

The final adjustment to the instrument may be made by the spacing screw from observation of signals transmitted at the full speed. The adoption of this systematic method will be found to result in better working and greater permanency of the adjustment when once made.

SPRING RECEIVERS, SPEED OF SLIP, AND FIGURES OF MERIT.

The earlier forms of Wheatstone receiver were worked by a spring instead of a weight and many of these instruments are in use at the present time upon less important circuits. They may be used in any case where the maximum speed required does not greatly exceed 200 words per minute. The speed of the slip when the lever is in the position for slowest speed should not be more than 8 feet per minute, and at highest speed not less than 36 feet a minute. The speeds of the slip with a weight-driven receiver should range from not more than 8 to not less than 60 feet per minute. The resistances of the coils are in each case the same, viz. 100^{ω} each, *i. e.* 200^{ω} in series and 50^{ω} in parallel. The figures of merit are also the same, 10 m.a. with the coils in parallel for key speed working, and 17·5 m.a. for the maximum speed of each instrument, but in this case a shunted condenser is employed, and the coils are placed in series.

THE MULLIGAN MOTOR-DRIVEN RECEIVER.

This arrangement provides for the direct driving of transmitters or receivers without intermediate gear by an electric motor of the variable-speed type, wound for a comparatively high voltage and run from a low-voltage battery, the motor being controlled by the usual governor of the receiver. There is nothing special about the motor, which originally was of the GM 2·5-series type, 110 volts, 1200 revolutions per minute, and was driven from any voltage ranging from 24 to 40 volts, the voltage being selected so that when run at "no load" the speed of the motor is substantially no higher than the maximum speed of the instrument it is to drive. But a later type of motor, viz. type GM 1·5, has given much more successful results, and this, which does not generally need a reduction in voltage, is now being adopted.

The system also provides for the motor-driven receiver to start and stop under the control of the transmitter, which control is effected by an electro-magnetic switch so designed that it is not affected by a train of marking currents.

The "underfeeding" of a motor was adopted to bring it more under the control of the ordinary Wheatstone governor, but this is now practicable with the smaller type motor without reducing the voltage, and the apparatus runs easily and regularly, and responds promptly to the Wheatstone speed-governor. Another feature is that existing apparatus may be easily adapted to this method of motor driving, and that is probably the main point in its favour.

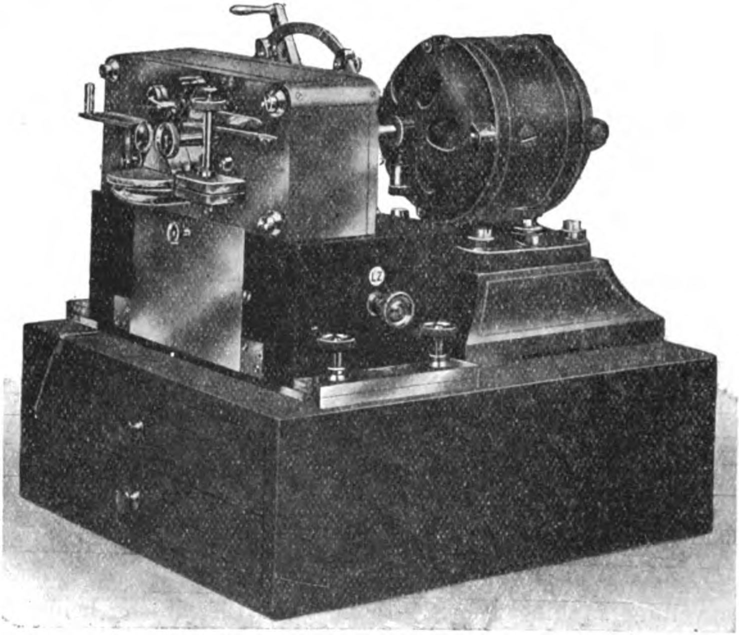

FIG. 198.—Mulligan motor-driven receiver.

Transmitters may, of course, be motor driven on the same principle, just as the Vyle and Smart system may equally be applied to receivers.

THE SHUNTED CONDENSER, SELF-INDUCTION, AND TIME-CONSTANT.

It is possible very greatly to reduce the retarding effect of self-induction by the use of a resistance and condenser of suitable values. The condenser is placed across the terminals of the resistance, and the arrangement as a whole is usually termed a "shunted condenser."

Before tracing the causes of the action mentioned it is desirable that the effect of inductance in delaying the rise of the current should be carefully examined. Let a battery, key, and an inductive resistance (a resistance having self-induction) be joined up in series. The value of the current given by applying Ohm's law represents the final or full value, but at the instant at which the key is closed the current is zero. The time taken for the current to rise to its full value or to any given percentage of its full value depends solely upon the inductance and resistance of the circuit. It is therefore quite independent of the value of the E.M.F. or current used. The "time-constant" of such a circuit" is defined as the time in seconds taken for the current to rise to ·632 (roughly $\frac{2}{3}$) of its maximum value, and is equal to the inductance (in henrys) divided by the resistance (in ohms) of the circuit.* Assuming that the inductance, say 3 henrys, is constant, and that the E.M.F. and resistance acting in the circuit are respectively 12 volts and 500^{ω}, the time-constant is $\frac{3}{500}$ = ·006 second. This is the time taken for the current to rise to approximately $\frac{2}{3}$ of its full value, *i.e.* to $\frac{2}{3}$ of $\frac{12}{500}$ ampere = 16 m.a. Had the E.M.F. of the battery been 24 volts the current would have been 32 m.a. ·006 second after the circuit had been completed.

It will be seen that any particular value of current may be obtained in any given time provided a large enough E.M.F. is employed. For instance, the current in the circuit described would be 16 m.a. in ·0006 second had 84·2 volts been used, or in ·00006 second with 162 volts.

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* Where an electromagnet with an iron core is concerned the inductance depends upon the value of the current, since the permeability of the iron varies with different values of magnetizing force. The inductance increases, due to the increase of the permeability, as the magnetizing force increases for all values ordinarily used in telegraphy.

USE OF SHUNTED CONDENSER TO BALANCE SELF-INDUCTION.

In Fig. 199 an *A* relay having an inductance of 3¼ henrys is shown in series with a shunted condenser, battery, and key. The capacity and resistance of the shunted condenser have been so arranged, that, when the key is released after depression the discharge of the condenser balances that of the relay. Whilst the key is depressed the condenser is charged by the difference of potential (20^{v}) existing between the ends of the 1000^{ω} resistance. If now the key is released the condenser discharges through the 1000^{ω} resistance, but in parallel with this is the 400^{ω} relay. The relay, having self-inductance, would generate an E.M.F. in the direction indicated by the dotted double arrow tending to prolong the main current. This E.M.F. is exactly balanced by that existing between the ends of the 1000^{ω} resistance depicted by the dotted single arrows. The current therefore sinks to zero at once, and prolongation of the current due to self-induction is eliminated.

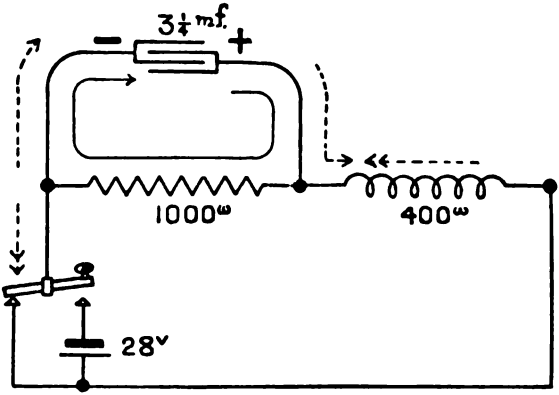

FIG. 199.—Use of shunted condenser to balance self-induction.

Whenever an arrangement having self-induction is balanced by a shunted condenser as described, the following relation always exists:—

The inductance in henrys is equal to the product *of the capacity in farads, and the square of the resistance shunting it, in ohms.*

In the present case the inductance (L) of the relay

$$= \cdot 00000325 \times 1000^2 = 3 \cdot 25 \text{ henrys.*}$$

The shunted condenser not only secures that the current through the electromagnet shall not be prolonged but it also hastens the rise of the current. It has previously been explained that a condenser connected across a resistance acts as a short circuit upon that resistance until charged. Taking the case of Fig. 199, the difference of potential between the ends of the relay (assuming the battery resistance as nothing) is 8 volts when the current has attained its full value of 20 m.a. But at the instant at which the key is depressed, this difference of potential is equal to the full E.M.F. of the battery, viz. 28 volts. From the investigations of page 349 it will be obvious that the current rises at a far higher rate than it would if the condenser were disconnected and the difference of potential between the ends of the relay did not exceed 8 volts.

When the condenser is fully charged the whole of the current passes through the 1000$^{\omega}$ resistance. Between this condition and that resulting at the instant when the key is depressed there are, of course, intermediate conditions. The action of the condenser can be made quite apparent by imagining that it is replaced by a resistance which increases in value from nothing to infinity (disconnection) during the time which the condenser takes to become fully charged. From this it is obvious that the difference of potential across the relay falls from 28 volts at the instant when the key is depressed to 8 volts when the condenser is fully charged.

ACTION OF SHUNTED CONDENSER IN WHEATSTONE WORKING.

In high-speed Wheatstone working a shunted condenser is invariably employed to enhance the speed of working.

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* The value of the current used must also be stated for the reason indicated in the footnote upon the previous page. The inductance of an *A* relay with coils in series is, according to the latest determination, 3·12 henrys at 5 m.a. and 3·55 henrys at 20 m.a.—*P.O.E.E. Journal*, Vol. IV. p. 311.

Upon a long circuit or upon one having considerable capacity its beneficial effects are produced by its action with or upon the static charge of the line. The general principle of the action can readily be explained but the rigorous mathematical proof is quite beyond the scope of the present work.*

The shaded triangle in Fig. 200 represents the value and distribution of the charge existing upon the wire when the positive pole of the battery is connected to line. The condenser is also charged in the direction indicated. At the instant when the battery is reversed and is connected as shown the conditions illustrated in the figure obtain. The condenser discharges into the line, thus producing a current through the receiver in the direction of the reversed battery and shown by the double-arrow. It must not be overlooked that the receiver possesses a considerable amount of inductance, and that, at the moment of reversal of the battery, the E.M.F. due to this cause comes into play in such a direction as would, in the absence of the shunted condenser, facilitate the passage of a portion of the static charge upon the line through the receiver coils, so causing prolongation and thereby diminishing the speed of working by reason of the increased time taken for the current in the receiver to change in direction. Even supposing that the receiver had negligible inductance, the shunted condenser would still produce highly beneficial results since it would reverse the current in the receiver immediately the battery was reversed and would prevent the line from discharging through the receiver. Under existing practical conditions its action is firstly to prevent the line discharging through the receiver —a tendency which would be aided by the E.M.F. of self-induction—and, having eliminated this, secondly, by its continued action creates a difference of potential across the terminals of the receiver which causes the current to rapidly rise to its full value in the reverse direction—in fact, this happens before the positive charge upon the line has been reversed in sign. The condenser acts instantly the battery is reversed and only ceases to act when fully charged in the reverse direction. It may be noted that the period of disconnection during which the lever of the transmitter is crossing from side to side is so small that the condenser is almost fully charged, since there is not time for it to discharge through its shunt.

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* The proof is given in an article in the *Electrical Review* of September 3, 1886, by W. Moon.

It will now be well to examine the effect of using too much and too little capacity in the condenser. The direct consequence of wrong adjustment is, of course, a reduction in the speed of working, but the effect upon the marks received may profitably be considered.

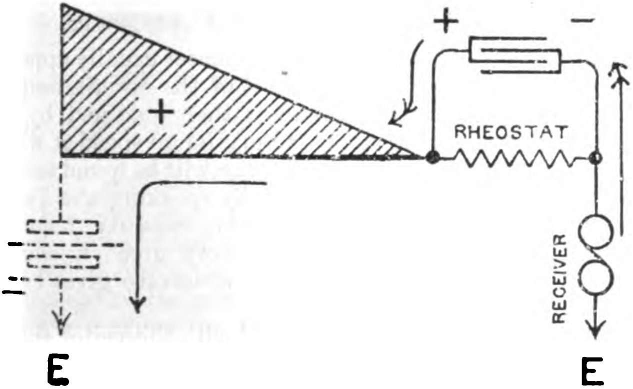

Fig. 200.—Principle of shunted condenser used upon a Wheatstone circuit.

In the Morse systems, whether automatic or key, the elementary signals (dots and dashes) are of unequal length. A dash means that the battery is applied for three times as long as for a dot. If, therefore, the letter "N" is sent the spacing current following the dash may not reverse the charge upon the line, and therefore the dash and the succeeding dot would run together, whilst "A" would probably be transformed into "T": *i.e.* a dot, following a spacing current of a duration equal to a dash, would be lost entirely. Again a "B" might be transformed into "G." It is this effect which the shunted condenser greatly remedies by coming into action instantly the battery is reversed. With too little capacity, then, a dot following a dash run together and a dot following a long space is lost.

If now the capacity of the condenser is too great the last dot of an "N" would disappear, and the dot and dash of an "A" would run together.

For any particular circuit there is always a best value to give to the capacity and resistance of the shunted condenser, and this may readily be found by the passage of working signals.

ADJUSTMENT OF SHUNTED CONDENSER.

The resistance in the shunted condenser usually approximates to the resistance of the rest of the circuit, and the value of the capacity required is then obtained by the passage of working signals at the maximum speed at which the circuit can be worked. The value will be found to vary for each particular circuit, generally speaking the longer the circuit the higher will be the capacity required. Where, however, the capacity is very great a smaller current and a much higher shunt resistance gives better results.

The value of the current received with the switch turned should be 16 m.a. with the coils in parallel, and the resistance in the rheostat should be reduced until this current (37° on the differential galvanometer with its coils in parallel) is obtained; with the receiver in series 8 m.a. (20° on the galvanometer) only is required. If the resistance in the rheostat has to be lowered to an amount altogether out of proportion to the resistance of the rest of the circuit the power should be increased.

ACTION OF SHUNTED CONDENSER UPON A VERY SHORT CIRCUIT.

The beneficial action of the shunted condenser is usually ascribed to its effect in neutralizing or rather mitigating the effects of self-induction in the receiver coils. This is, however, only true where the circuit is very short and has practically no capacity.

Upon such a circuit, having little or no capacity, a shunted condenser effects a small economy in battery power. By disconnecting the condenser and increasing the battery power the same speed can be obtained as with the condenser. The effects of self-induction can always be smothered by introducing resistance into the circuit and raising the battery power. The time-constant of the circuit may be thus reduced to any required extent. For instance, the time-constant of a circuit containing a battery (100^{ω} resistance) and a receiver in series is $\frac{3\cdot25}{300} = \cdot01083$ second, with a resistance of 1700^{ω} added it is $\frac{3\cdot25}{2000} = \cdot001625$ second, assuming that the value of the current is the same in each case.

RESISTANCE OF SENDING CIRCUIT.

It has previously been stated that each coil of the differential galvanometer (50^{ω}) is shunted by a 300^{ω} resistance coil in order to reduce the inductance. It is also pointed out in the subsequent chapter that one of the chief advantages gained by bridge duplex working lies in the fact that the currents sent out do not encounter the self-inductance of the home receiver. Moreover, the beneficial effect of the signalling condenser is accountable to its action in temporarily reducing the effective resistance of the sending circuit. In order that a signal may be formed upon the distant receiver in the shortest possible time, the resistance of the sending circuit should be as low as possible, subject to the qualification that it shall not be so small as to cause the transmitter to spark (see page 629). The effect of self-induction in the sending circuit is even more serious, and it is upon this account that the coils are shunted as already explained. They are also invariably joined up in parallel, thereby reducing both the resistance and inductance of the instrument to one-fourth of the value which it would have with the coils in series.

It will now be realized that the use of Daniell batteries upon a Wheatstone circuit would result in a serious reduction of the working speed owing to the larger internal resistance involved in providing the requisite E.M.F.

TRANSMITTER SWITCH.

The lever provided for stopping and starting the transmitter also operates the switch referred to on page 339.

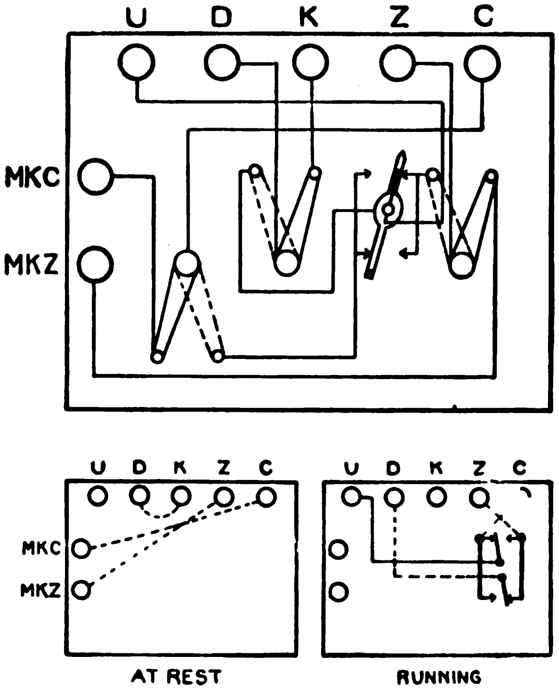

FIG. 201.—Wheatstone transmitter, internal and skeleton connections.

When the transmitter is not actually running this switch joins the battery through to *Z* and *C* of the double current key provided for making or answering calls and for the sending of acknowledgments. Also it joins the down line through to the lower right terminal of the key. The connections of the transmitter with its switch are depicted in

Fig. 201. The switch consists practically of three two-way switches mechanically connected together. The first and third levers in the positions shown join the battery terminals *Z* and *C* through to *M K Z* and *M K C*, which are connected to *Z* and *C* of the key. In the other position (when the transmitter is started) the battery (at *Z* and *C*) is connected to the battery contact screws, thus forming the connections depicted in skeleton in the lower right-hand portion of Fig. 201. The second lever normally connects the down line, which has passed the galvanometer, through to *K*, which is in turn connected to the lower right terminal of the key. In the other position the down line is joined to the lower half of the divided lever. The up line terminal of the transmitter *U* is connected to the left side of the key and *U* of the receiver or *U*-circle of the relay as the case may be. Comparison of Figs. 128 and 201 will show that when the transmitter is stopped the connections are practically those of the double current sounder save that a shunted condenser is included and a receiver substituted for the relay.

CONNECTIONS OF A FULL WHEATSTONE SET.

The connections of a full Wheatstone set are depicted in Fig. 202, and, with the aid of the above explanation, they should be sufficiently clear and easy to memorize.

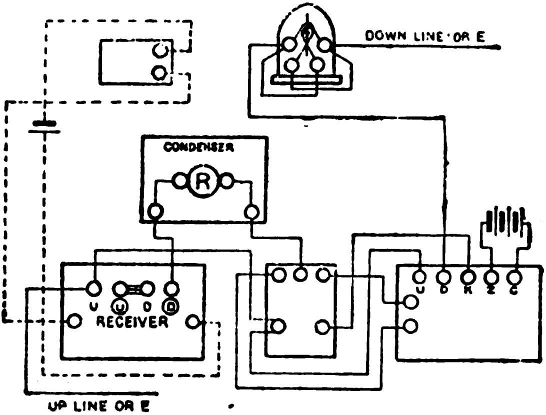

FIG. 202.—Wheatstone simplex connection.

The path of a received spacing current is from the down line through the galvanometer to *D* of the transmitter, to *K*, to lower right terminal, and to centre of the key, through the shunted condenser and receiver, to the up line.

The transmitter currents are sent out between *U* and *D* of the transmitter, and, to make a mark, the positive pole of the battery is joined to *D* and the negative to *U*. The key currents should require no comment.

Here it will be well to state that the metal case of the transmitter is earthed so that, in the event of defective insulation, the telegraphist may not receive a shock by touching the frame. The earth connection is made by means of an extra terminal added to the transmitter for this purpose.

ADDING A TRANSMITTER TO A KEY-WORKED CIRCUIT.

In order to add a transmitter to a key-worked circuit to meet a temporary requirement, a transmitter stool should be obtained so as to avoid cutting the tables to receive the weight chains. The two wires upon *Z* and *C* of the key should be removed from their terminals and extended by pieces of wire respectively to *Z* and *C* of the transmitter. *Z* and *C* of the key should then be connected to *M K Z* and *M K C*. The wire upon the lower right-hand terminal of the key should similarly be disconnected and then joined to *D* of the transmitter. *K* should then be connected to the lower right terminal of the key. Finally, *U* of the transmitter should be joined to the lower left terminal of the key, leaving the wire already upon that terminal in its position.

SUBSTITUTION OF A RECEIVER FOR A RELAY.

In substituting a receiver for a relay a similar procedure should be followed. If a spring receiver will not meet the case as regards the speed required a stool should be obtained in preference to cutting the tables for temporary requirements. It should be noted that the *U* terminal of the receiver is on the left, whilst on a relay it is on the right. This is of course due to the fact that in the former case the tongue normally lies over to the right. The wire on *U*-circle of the relay is joined to *U* of the receiver, and the *D* wire to *D*-circle. The local circuit is quite obvious.

THE WHEATSTONE DUPLEX.

The Wheatstone system can be duplexed upon either the differential or bridge method, and the connections required in the former case may readily be deduced by comparing Figs. 148 and 202. There are, however, three points which require to be especially noticed. Firstly, a battery switch is provided for cutting out the battery and inserting a resistance equal to its internal resistance. In the older arrangements this was accomplished by means of a 6-terminal two-position switch of the same type as that used to convert the set from simplex to duplex (see Fig. 135). In later arrangements a two-way switch serves the same purpose, the negative pole of the battery being connected to *Z* of the transmitter, and also to the left side of the battery resistance coils. The positive pole takes the right side of the two-way switch, the lever being joined to *C* of the transmitter. Secondly, the condenser and rheostat are in circuit at simplex, so that the arrangement may be used as a shunted condenser and so provide a higher working speed. This is effected by a slight alteration in the connections upon the duplex switch. Referring back to Fig. 148 of the double current duplex connections it will be seen that *D* of the relay is joined to the top centre of the duplex switch, the upper left terminal of which goes to the key and the right to the rheostat. Now in order to have the condenser and rheostat in circuit for both simplex and duplex, it is only necessary to join them between *D* of the relay and the centre terminal of the switch and take the right terminal direct to the galvanometer. The alteration necessary is shown in principle in Figs. 203 and 204. Thirdly, in order that the adjustment of the receiver may be the same for both duplex and simplex working a resistance coil is inserted between the *U* terminal of the receiver and junction of the two wires connected to it. When the resistance of the line is 1000^{ω} or less, a 1000^{ω} resistance coil is used, but where the line resistance exceeds this amount, 2000^{ω} is inserted. It will therefore be seen that although the received current passes through both coils in series the resistance of the circuit is practically doubled, thus halving the current and so making its magnetic effect upon the receiver practically the same as in duplex working.

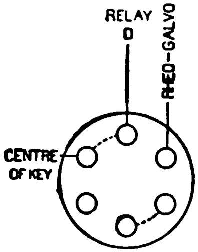

Fig. 203.—Duplex switch connections upon a key-worked circuit.

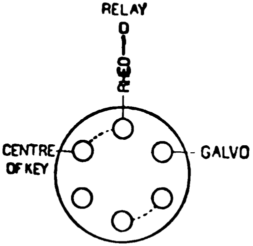

Fig. 204.—Duplex switch connections for a Wheatstone duplex circuit.

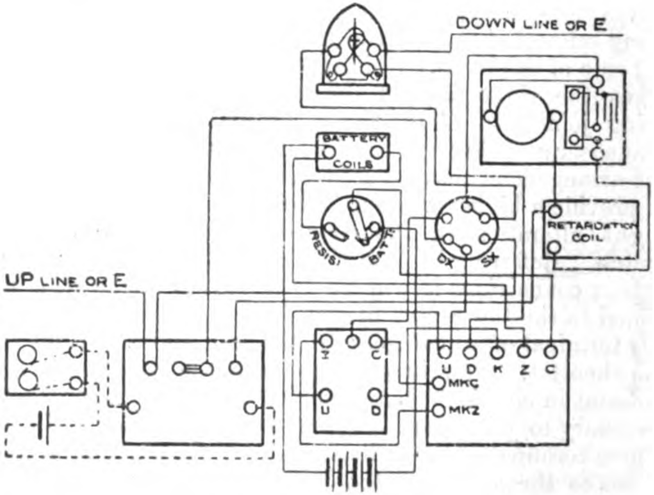

Fig. 205.—Connections of a Wheatstone duplex circuit.

The connections of the receiver which replaces the relay are quite obvious, and those of the transmitter are readily deduced from the simplex Wheatstone set already described. Transmitter *U* and the lower left terminal of the double current key are joined together at the lower centre terminal of the duplex switch. The galvanometer split wire comes to *D* of the transmitter and is normally passed on to the lower right terminal of the key via *K*. If the above explanations are clearly apprehended the connections of a Wheatstone duplex are as easy to remember as those of a double current duplex. The connections are shown in full in Fig. 205.

DIFFERENTIAL DUPLEX WITH SIGNALLING AND READING CONDENSERS.

An improved form of Wheatstone differential duplex is occasionally used upon cable circuits, and consists in the addition of signalling and reading condensers to the ordinary duplex arrangements. The duplex connections are accurately shown in skeleton in Fig. 206. Two resistances each of 3000^{ω} are placed in series with each coil of the receiver, and their junction forms, as the case may be, a splitting or combining point for the key currents. The two signalling condensers are joined between this point and the ends of the two coils of the receiver. This action is identical with that of the signalling condenser used in bridge duplex working (see page 390), viz. to apply the full E.M.F. of the battery to the line until the current in the distant

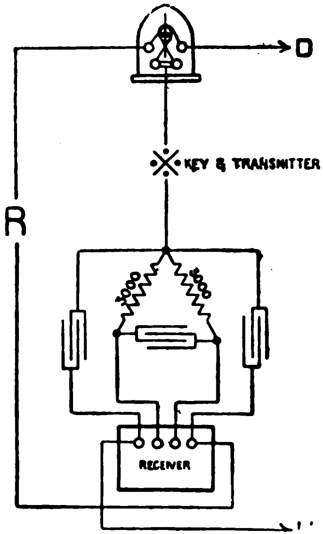

FIG. 206.—Principle of a differential duplex with signalling condensers.

apparatus has risen to the value which is obtained when the condenser is charged and the duplex resistance coils are traversed by the current (the E.M.F. applied to the line is then less than the full E.M.F. of the battery).

The reading condenser is to hasten the rise of the received current by short-circuiting the duplex coils until charged. Also it reduces the short-circuiting effect of the signalling condensers upon the received signals.

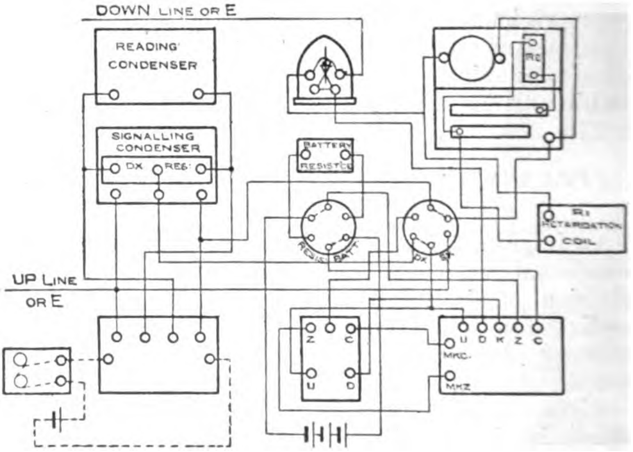

Fig. 207.—Connections of differential duplex with signalling condensers.

All the condensers assist the reversal of the current by their discharges. They, as it were, "suck out" the static charge upon the line.

The full connections of the set are indicated in Fig. 207, and will readily be comprehended by aid of the skeleton diagram and the previous consideration of Wheatstone working as a whole.

NEWS CIRCUITS AND BATTERY POWER REQUIRED.

For "news" circuits a transmitter is required at the sending station, and receivers at the terminal and intermediate stations. The terminal station only is provided with a shunted condenser. In practice a minimum of

100 volts (secondary cells) or its equivalent in No. 1 cells is generally employed, and the resistance of the circuit is, if necessary, raised by the rheostat upon the shunted condenser until the required current is attained.

The reason for employing a minimum E.M.F. of 100 volts for operating Wheatstone circuits, both simplex and duplex, lies in the fact that with lower voltages the resistance of the contacts made by the divided lever of the transmitter have an abnormally high value, so reducing the current to too small a value for high speed working. There are, however, some few cases in practice in which only 80ᵛ is used.

*THE CREED RECEIVING PERFORATOR.**

This machine, the invention of F. G. Creed, is known as the Creed receiving perforator. It reproduces, at any speed up to 200 words per minute as a maximum, an exact replica of the Wheatstone perforated tape prepared at the sending end of the circuit. The mechanism for accomplishing this provides for:

(*a*) Actuating punches under the control of, and in correspondence with, the line signals from the tape at the sending station.

(*b*) Moving the receiving tape past the punches at a uniform speed approximating to that of the transmitter.

(*c*) Momentarily arresting and holding the tape before and during the act of punching, and then releasing it promptly.

In order to accomplish (*a*) and (*c*), compressed air is employed; and for (*b*) a friction drive for the tape is used in conjunction with holding and releasing devices described later.

The construction of the apparatus is shown diagrammatically in Fig. 208. "*A*" represents a Post Office standard relay without any electrical contacts. Its armature *b* is provided with a light tongue 1, to the free end of which is attached an exceedingly light balanced slide valve 2; this is adapted to control the supply of air to the small relay engine 3, the piston 3*a* of which is thus moved from side to side, in accordance with the line signals which actuate the relay tongue. The movements of the piston 3*a* are transmitted by means of the rocking levers 4 to the piston-valve 5 of the main engine, thus controlling the double-acting piston 6. From each side of this piston a rod projects through the cylinder cover and thrusts in either direction the adjacent arms of the three-armed bell-crank levers 7 and 8. Upon the arms 10 and 11 are hard steel strikers 12 and 13, the free ends of which are bifurcated for the purpose of thrusting against the adjacent heads of the corrector rods 14 and punches 15. These rods and punches are mounted and guided in a

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* From the *Electrical Review*. See also "The Creed Telegraph System," by E. Lack, *P.O.E.E. Journal*, Vol. VI. p. 249.

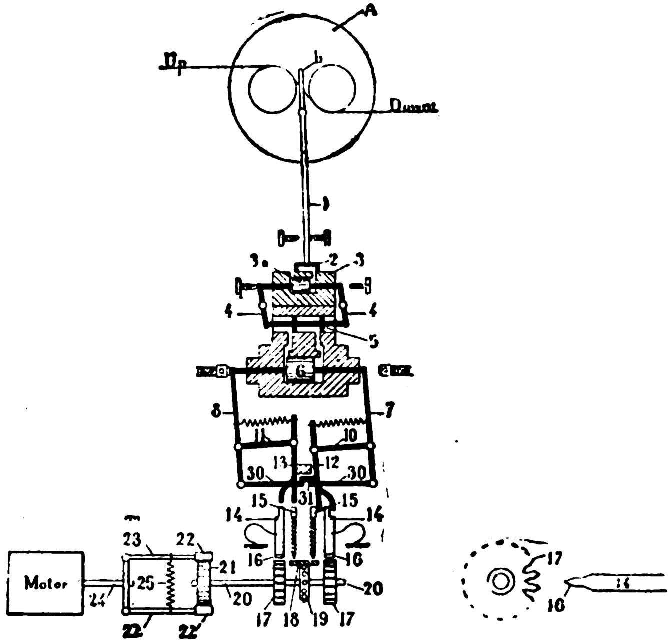

Fig. 208.—Principle of Creed receiving perforator.

separate block, with the die plates and the feed wheel spindle. The corrector rods 14 have flattened points 16, terminating in a V-shape (shown separately), and when thrust forward are adapted to enter the slots in the correcting wheels 17. Retracting springs are provided, as shown, to restore the rods and punches to their normal position against stops. The paper strip 18, which is previously centre-holed, is led up between the die-plates, past the punches, and engages with the feed wheel 19, mounted upon the spindle 20, to which the correcting wheels 17 are also fixed. When the points 16 of either correcting rod 14 are thrust by the striker between the teeth of the wheel 17, the rod adjusts and holds the latter, as well as the feed wheel 19, and the tape, in such a position that the corresponding punch 15 will perforate the paper exactly opposite the feed holes. Mounted upon an extension of spindle 20 is a friction disc 21, driven by the friction blocks 22, fixed upon the pivoted arms 23, which are attached to the motor-driven spindle 24. This spindle rotates the feed wheel 19 at approximately the same rate as the feed wheel of the transmitter. For adjusting the driving tension the spring 25 is arranged to slide longitudinally on the rods 23.

The action of the machine is as follows: A line "marking" current in the relay coils moves the armature *b* to the right, causing the tongue 1 to move the valve sharply to the left. The piston 3*a* of the relay engine is thus caused to move to the right, and the valve of the main engine in the opposite direction. This causes the main piston to be driven to the right. The movement is transmitted by means of the bell-crank 7 and the link 30 to the bell-crank 8, which in turn causes the left-hand striker 13 to thrust the tooth of rod 14 between the teeth of the wheel 17, adjusting, if necessary, the position of the feed wheel, and forcing the corresponding punch 15 through the tape 18. The tappet piece 31 formed on the link 30 now comes in contact with the striker, forcing it from the rod and punch, and permitting them to spring back to their normal position. On the reversal of the line current the relay tongue is moved in the opposite direction, causing a reversal of the engine, when another operation similar to that described is performed by the right-hand striker 12 upon the right-hand corrector rod and punch.

As the complete operation of thrusting and releasing the punches occupies only the 300th part of a second, the time during which the feed-wheel is arrested is practically negligible, and the difference between dots and dashes in the tape depends entirely, therefore, upon the time-interval between successive spacing and marking contacts during which the tape is allowed to run on. Even between the marking and spacing currents for a dot, there is an appreciable interval during which the slip has travelled a little. The right-hand punch, and corresponding correcting wheel, are given a lead, so that, although the spacing punch is actuated later, the spacing perforation appears opposite the same centre-hole as the marking perforation.

In the earlier forms of the Creed receiver a much larger electrical relay was used to actuate directly the valve of the main engine; but, as the speed attainable by this arrangement was limited, and the current required was considerable, the relay engine was introduced with excellent results, a maximum test speed of 225 words per minute being attainable with an air pressure of 30 lbs. per square inch, and a working current of 15 to 20 milli-amperes in the relay.

The object of the Creed receiver is to save manual labour in the reception and re-transmission of telegrams. In cases where messages are to be printed for delivery at the office where they are received the perforated slip obtained from the receiver is passed immediately through the Creed printer, which, under the influence of the perforated tape, prints the message on another strip of paper in Roman characters. This can be done at the rate of over 100 words per minute, and at very busy circuits two telegraphists can thus receive two or three hundred messages per hour.

In re-transmission in the ordinary way, telegrams from a chief centre *A* to a minor office *C* have to be received by an intermediate office *B*, written up and re-transmitted

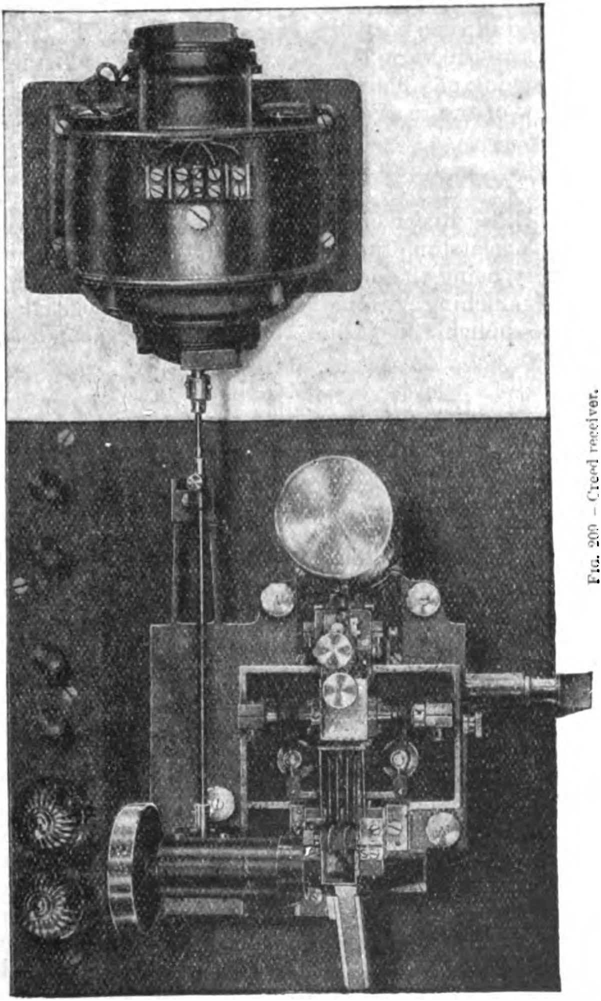

Fig. 200 – Creed receiver.

to *C*. By means of the Creed machine, the received perforated slip can be passed through the transmitter on the *B C* line. In the case of press work, *B* may be the transmitting centre for several offices, and the one received perforated slip can be utilized for automatically distributing the news to the various offices. At the centre *B* there is thus a saving of labour.

A view of the receiving perforator is given in Fig. 209.

THE BILLE RECEIVING PERFORATOR.

The Bille Receiver, like the Creed, reproduces perforated Wheatstone tape but does not use compressed air, electricity being the only power required.

The punching arrangement for each positive and negative punch consists of three parts, *h*, *o*, and *m*, on Fig. 210; *h* is a hammer provided with a small roller, *g*, at the far end, and kept back from the bellcrank, *o*, by a spring, *k*. The disc, *c*, mounted on the spindle, *a*, and driven by a motor coupled to the other end of the spindle, carries three cams, of which two, *e* and *f*, are shown. Two

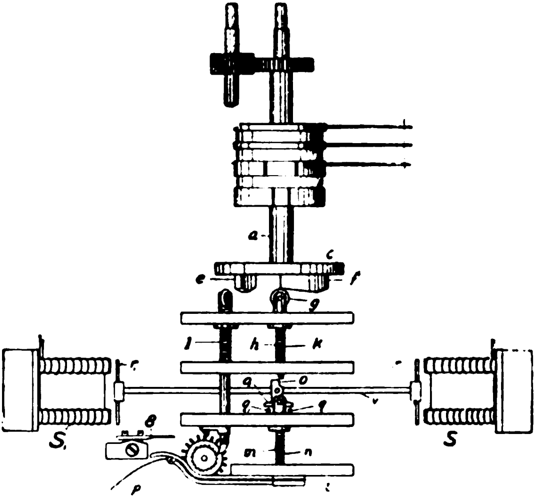

Fig. 210.—Principle of Bille receiving perforator.

of these cams are placed diametrically opposite each other, but at different distances from the centre of the disc. During a revolution of the disc one of these two cams will pass over the roller, *g*, and cause the hammer to be pressed towards the bellcrank, *o*. This bellcrank turns on a pin mounted in the head of the punch, *m*, and is controlled by a rod, *v*, whose other end is fastened to the armature, *r*. When this armature is attracted by the electromagnet, *S*, the free end of the bellcrank will be brought into line with the hammer, *h*, which in its forward movement will press against the free end of the bellcrank, and so actuate the punch, *m*, and a perforation will take place in the tape, *p*, which passes from right to left through a slot, *t*. The bellcrank, *o*, when being pushed forward, will turn on its pin when it meets the small stud, *q*, and thereby be thrown out of touch with hammer and punch, which will be returned to their normal positions by their respective springs, *k* and *n*. Therefore, during each revolution the hammer will be pressed forward, but a perforation will only be made if the electromagnet's armature has brought the bellcrank into line with the hammer and the punch.

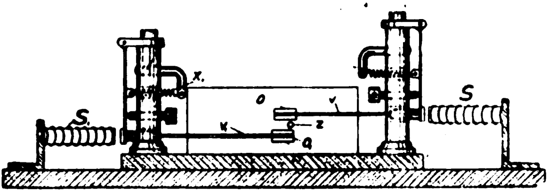

FIG. 211.—Principle of Bille receiving perforator.

A sectional view of the electromagnet, armature, lever and bellcrank is shown in Fig. 211. The spring, *x*, keeps the armature back from the pole pieces, and the tension of this spring must therefore be overcome by *S* in order that the bellcrank may be placed in the punching position. What has been described is the positive system, consisting of cam, hammer bellcrank and punch. The negative, actuated by the cam on the disc, *c*, opposite the positive cam, is arranged similarly, but below the positive, and the electro-magnet is on the left of the machine (*see* Fig 211)

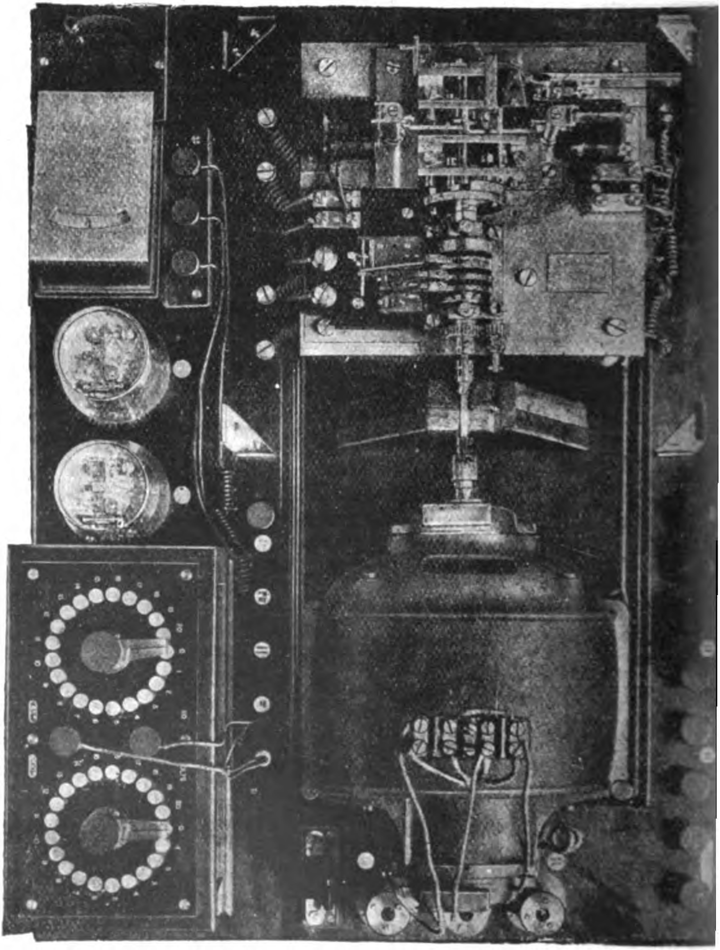

Fig. 212.—Bille receiving perforator.

Attached to the positive hammer is the centre-hole punch, indicated at *z* in Fig. 211. During each revolution, therefore, a centre hole will be perforated, whether or not the positive or negative punches are actuated.

The third cam on the disc, *c*, passes over the roller at the end of the rod 1, to the left of the punching mechanism. At the other end of the rod is fixed a pawl, which actuates a ratchet wheel mounted on the same spindle as the feed wheel, which pulls the paper a tenth of an inch during each revolution of the disc, *c*. A jockey roller, attached to the flat spring, 8, assures a regular movement of the feed wheel.

S and S_1 receive their impulses from any ordinary polarized relay through a condenser, and the armatures, r, r_1, forming a magnetic circuit with the pole pieces, keep the bellcranks, o and o_1, in a punching position until thrown off by the studs, q and q_1.

The regular running of the motor is ensured by a simple synchronising device (part of which is shown behind the disc, *c*, in Fig. 210), arranged to increase or decrease the speed of the motor by automatically inserting a resistance in series either with its field or armature windings.

THE CREED TELEGRAPH PRINTER.*

The received perforated tape is passed through the printer which typewrites the message in Roman characters on a tape, which is then gummed on to a telegraph form.

A diagrammatic explanation of the action of the printer is given in Fig. 213, and a view of the complete machine in Fig. 214.

The received perforated slip is passed into the machine at *A* (Fig. 213) and out at *B*; while the slip on which the printing takes place is drawn by a pair of feed-rollers from the roll of the upper left-hand side, between the connecting rods of the type-bars and over the printing platen.

The perforated tape is fed forward letter by letter in a

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* *Electrical Review*, September 25, 1908.

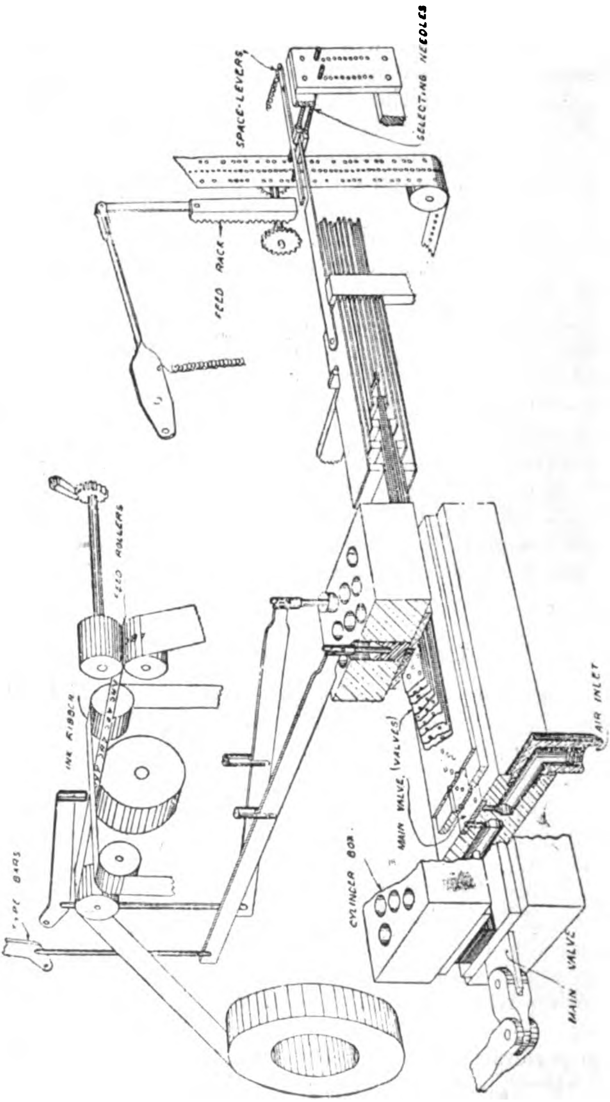

FIG. 213.—Action of Creed telegraph printer.

guide-way in front of a series of ten pairs of selecting needles, one needle of each pair being mechanically connected to a series of ten slide-valve plates. Each of these valve plates can be made to occupy one of two positions,

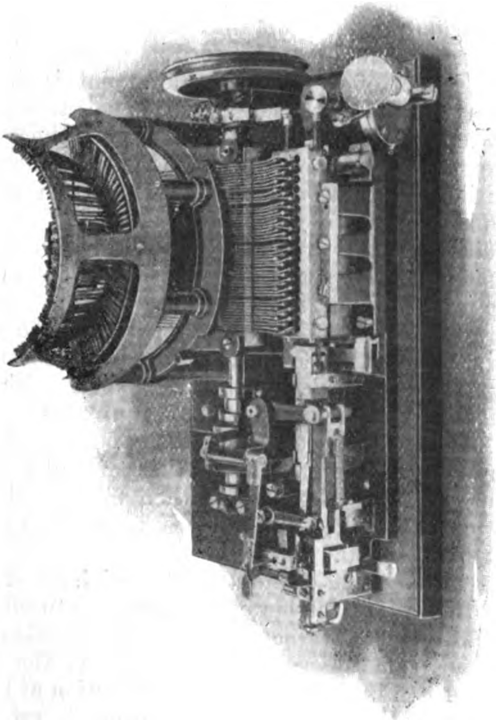

Fig. 214.—Creed printer. (A small compressor is embodied in the design to avoid the use of an external pressure supply.)

thus providing a number of different combinations, every one of which opens one complete and particular passage through the ten slide-valve plates. Air under pressure can thus be admitted to any one of a number of small cylinders, each containing a piston acting on the end of a lever connected to a type-bar.

The perforated slip is fed forward by a star wheel fitted to a spindle carrying a toothed wheel, which is rotated as required by the movement of a rack. The rack is given a vertical motion for feeding purposes, and a sidewise motion for acting on any slide-valves that may have been selected. Its movement is obtained from the cam-shaft of the machine, which is belt-driven from a small electric motor. The extent of the vertical movement is limited by the distance to the first space signal, that is to say, the length of a letter. To provide for this limit there is a group of ten space levers normally in the path of the rack, and preventing its downward movement. Each space-lever is also in the path of one pair of selecting needles, and when either needle of a pair passes through a perforation, that particular space lever is moved out of the path of the rack. Hence, with any letter or figure of the Morse code there is a clear downward path for the feed-rack until it reaches a space signal. A sidewise movement is then given to the rack, putting it in gear with the toothed wheel. Next, the rack is given an upward motion, causing the toothed wheel to turn and the perforated tape to be fed upward by the amount of the particular letter that has just passed. The rack is then moved sidewise again, clear of the toothed wheel, ready to descend as far as the next space signal.

The slide-valves made of thin sheet-steel have each a hinged extension whose further end is arranged to take up the movement of the corresponding selecting needle in its motion to and from the perforated tape. At the same time, the extension is free to move in a direction at right-angles to the needle. Each valve-extension is provided with a shoulder which comes into the sidewise path of the feed rack when that particular extension has been selected. At the correct moment, determined by the position of a cam on the main spindle, the rack is moved sidewise, and engaging with the shoulders of the valve extensions which have been selected, moves the corresponding slide-valves into their second position. Another cam opens a main valve, admitting air under pressure to the slide-valve chamber, whence it passes through the ten valve plates by the one hole available in that particular setting of the valves, forces up the particular piston and prints the corresponding letter. Another main valve is then opened to allow the air to escape, and the selected slide-valves are returned to their normal position.

Although more than the required number of selecting needles for any particular letter may pass through the tape, only the proper number of slide-valves are acted upon by the rack, on account of the spacing lever preventing the rack descending beyond the required amount.

It will be observed that there are twenty selecting needles, but only the ten acting on the lower row of holes in the perforated slip are attached to valves; the other row of needles is not necessary for selecting purposes, but is required for shifting the spacing levers for the first portion of a dash signal.

The machine prints satisfactorily at any speed up to 125 words per minute; but this is not the maximum, it being considered possible to reach 150 with the present form of machine, and this may possibly be increased with improvements in details.

This system of telegraph printing has the advantage of using the Morse code, thus entailing no alteration of existing telegraphic apparatus. Intermediate stations, such as repeater stations or testing points, can check the passage of the signals without any knowledge of the Creed system, and can make all necessary adjustments without reference to the terminal stations. The system, being an addition to the Wheatstone system, can be introduced gradually without disarranging any of the present Morse methods.

THE CREED TRANSLATOR.*

There is another remarkable instrument which it will be interesting to notice, although its consideration scarcely comes within the scope of the present volume. In order to prepare the perforated slip required for the transmission of the positive and negative impulses, each of equal duration, over long submarine cables worked with the siphon recorder a special form of perforator is employed. The difference in the character of the perforations will be obvious from a consideration of *X* and *Y* in Fig. 215, where at *Y* the upper holes represent positive and the lower negative currents. By passing the ordinary perforated Wheatstone slip through the translator a second slip perforated for cable transmission is automatically prepared. It will thus be apparent that if a Creed receiving perforator be employed at a cable handing-over station, the received slip can be passed on to the translator set to run at a slightly higher speed than the receiving perforator, thus keeping the slip always in tension, and thereby producing more or less friction on the drum of the driving spindle. In this way the speed of the translator is reduced to that of the receiver. The tape emerging from the translator is then passed through the cable transmitter and the signals emerge at the distant end in the well-known and characteristic wavy line of the siphon recorder.

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* A full description appears in the *Electrical Review* of December 4, 1908.

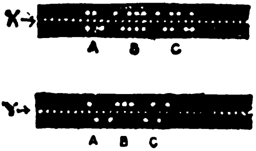

Fig. 215.—Slips for Wheatstone and cable transmission.

The Siemens Electromagnetic Receiving Perforator.

This instrument (Fig. 216) perforates a slip at the receiving station for retransmission. The tape may be passed slowly through a transmitter and read by sound when retransmission is not required. The apparatus consists of two electromagnets, two corresponding armatures with levers, punchblock with two punches, "marking" and "spacing," paper-guiding and propelling gear and motor. A marking current brings the tongue of the line relay (Fig. 217) to the marking contact, charges a condenser and energizes the corresponding electromagnet, which thus punches a marking hole. On the cessation of the marking current the tongue of the relay moves to the spacing contact: this causes the condenser to discharge by way of the second electromagnet, which promptly operates the corresponding punch, producing a spacing hole. The action of the

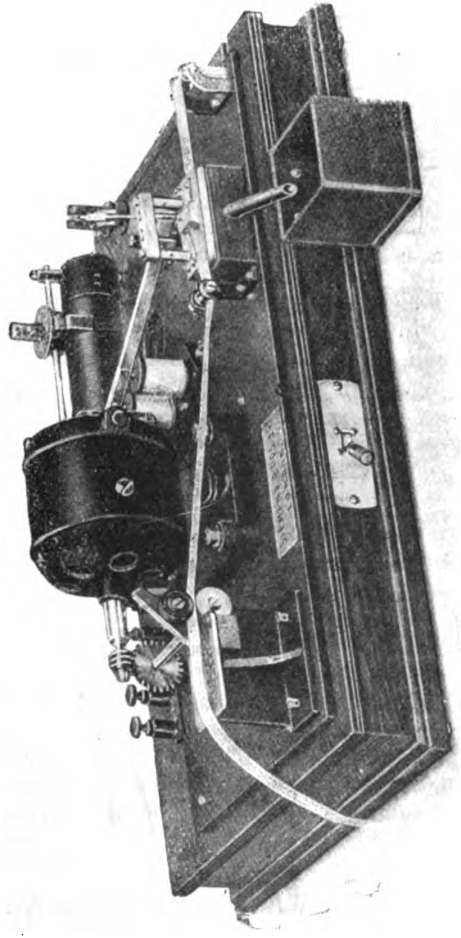

FIG. 215.—Siemens electromagnetic receiving perforator.

punch-magnet is so quick that no tearing of the moving paper-tape takes place. The perforations produced by this machine are somewhat similar to those of the usual Wheatstone type, only slightly on the slant; thus a Siemens "dot" signal looks somewhat like the Wheatstone "dash," while the "dash" is like an exaggerated Wheatstone dash, viz. the spacing hole relatively more to the right (Fig. 218). There are no central or guiding holes, as the Siemens morse transmitter works without star wheel.

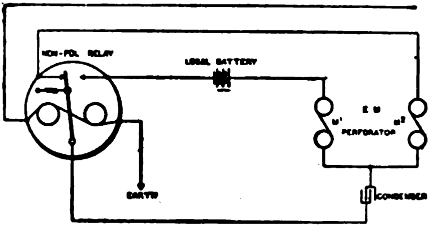

Fig. 217.—Principle of Siemens receiving perforator.

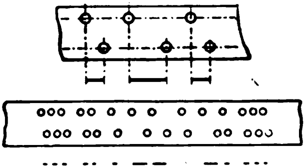

Fig. 218.—Siemens perforated slip.

On long lines, a polarized relay and local circuit are employed to operate the non-polarized relay.

The apparatus is capable of 80 to 100 words per minute. Perforated slip can of course be obtained by substituting a key and local battery for the local contacts of the line relay.

Siemens Automatic Wheatstone Transmitter.

Instead of the two reciprocating needles of the Wheatstone transmitter, two contact springs are arranged side by side with projections which drop into the holes of the slip alternately. One spring is slightly in advance of the other. A polarized relay (Fig. 219) is operated by the charging and discharging current of a condenser from a local battery under the control of the two aforementioned contact springs by means of a commutator situated at the end of the motor spindle. The tongue of the relay is connected to line, while marking and spacing contacts are respectively connected to positive and negative voltages. Immediately the marking spring drops into a hole in the perforated slip the local current (as directed by the commutator) brings the tongue of the relay to marking, and at the same time charges the condenser. Hereupon the commutator connects the relay to the spacing spring, and immediately a spacing hole causes the spring to drop and make contact, whilst the condenser discharges and throws the tongue of the relay over to the spacing contact.

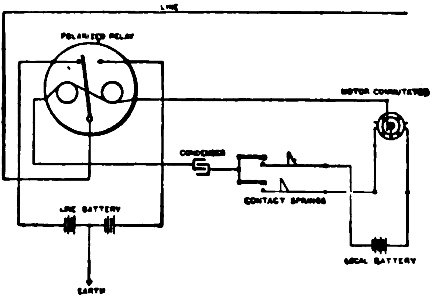

Fig. 219.—Principle of Siemens automatic Wheatstone transmitter.

For every revolution of the motor the perforated paper travels the distance between two guiding holes, whilst the charging and discharging commutator connections are made at each half-revolution for a period of a quarter fo a revolution.

The Siemens Automatic Morse Transmitter.

A simple change in the tape-propelling gear, and by adjustment of the contact springs the Siemens-Wheat-

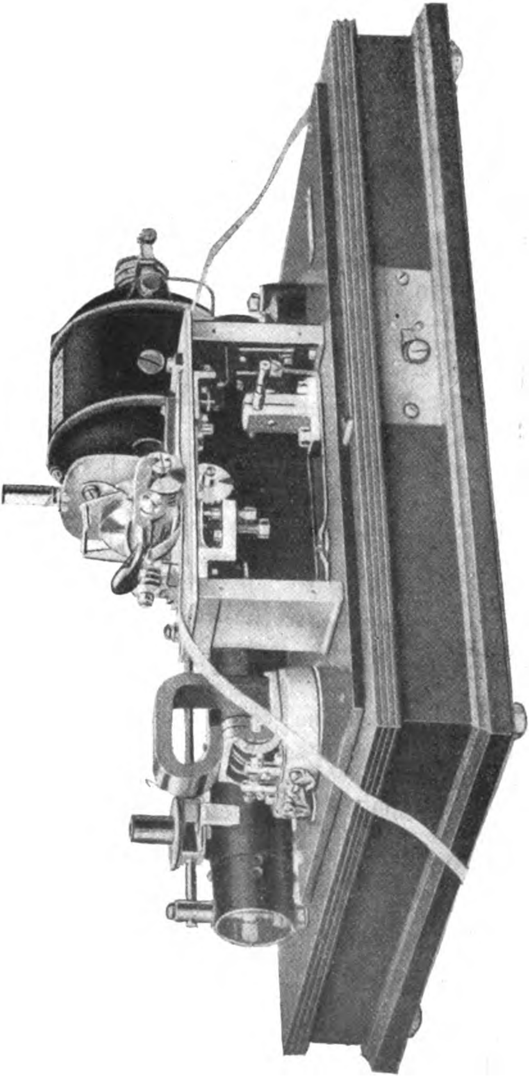

FIG. 220.—View of the Siemens automatic transmitter.

stone automatic transmitter can be arranged to run with Siemens perforated slip (Fig. 218). The apparatus, termed Siemens automatic Morse transmitter, works without star wheel, an ordinary friction-propelling gear taking its place: further, the timing of the charging and discharging currents is not controlled by a revolving commutator as in the Siemens-Wheatstone apparatus, but the respective actions take place immediately on one or the other of the two springs dropping into a hole of the perforated tape and making the necessary contacts (Fig. 221).

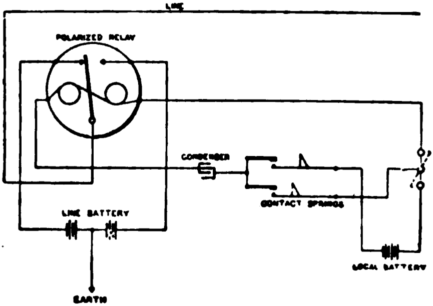

Fig. 221.—Connections of Siemens automatic Morse transmitter.

The speed of the perforated tape can be regulated electrically by means of a sliding rheostat, and mechanically by means of a brake which is attached to the motor spindle.

CHAPTER XI

THE BRIDGE DUPLEX.

THE Bridge duplex system is invariably used for Wheatstone working upon cable circuits. Upon such lines, where the capacity is much greater than upon open lines, a higher speed of working is attained than that which results when the previously described differential duplex is employed. For even the longest aërial lines it possesses absolutely no advantage over the differential system, but on the contrary entails the use of larger battery power.

ADVANTAGES OF THE SYSTEM.

The enhanced speed of working upon cable circuits is due to the fact that the sender's current does not pass through the relay or receiver at the sending end and to the application of signalling and reading condensers.

The advantages of the bridge system may be summarized as under:—

1. Permits the application of signalling and reading condensers.

2. The minimum amount of retardation is introduced in the sending circuit, since the current flows direct to line and does not pass through an electromagnet at the sending end.

3. The apparatus required need not be differentially wound.

4. Two different types of instrument may be worked upon the one circuit.

5. The effects of earth currents are not felt so much in bridge as in differential duplex working.

The advantages gained under headings 1 and 2 result in a considerable increase in the speed of working, but at the expense of increased battery power. The advantage of using apparatus not differentially wound is in this country quite problematical, since all the relays used by the Post Office are invariably so wound. The fourth claim is true but it does not seem probable that it could ever be desired to work, say, Morse in one direction and Hughes in the other. The fifth point will be apparent when it is remembered that the resistance of the circuit as a whole is very high, and that only a portion of the line current passes through the receiver.

General Principle.

After the detailed consideration accorded to the differential duplex but little difficulty will be found in dealing with the bridge duplex. The differential system consists in splitting the sending current through the two coils of a differentially wound relay, the effects produced being the result of disturbances of the balance of current in the two coils. In the bridge system the current divides through two resistance coils to the line and compensation circuits between which the receiving apparatus is placed. If the ends of the two resistance coils are at the same potential no current will flow through the receiver. Hence it is usual to say that the differential system depends upon a balance of currents and that the bridge system in contradistinction depends upon a balance of potentials.

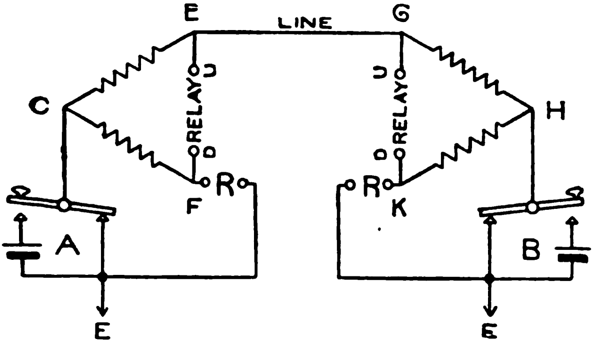

Fig. 222.—Principle of Bridge duplex.

The connections depicted in Fig. 222 illustrate the fundamental principle of this system as compared with the differential duplex (see Fig. 131).

C E and *C F* are two equal resistances, between which the receiving apparatus is connected. *R* represents a resistance equal to that of the line *plus* the resistance of the distant apparatus. The connections at both ends are identical, *G H* and *H K* corresponding to *C E* and *C F*.

If the key at *A* is depressed the current divides equally between *C E* and *C F* because the resistance of *R* is equal to that of the line and *B*'s apparatus. Since the resistances of *C E* and *C F* are equal, the differences of potential between *C* and *E* and between *C* and *F* are equal, consequently, when only one key is depressed, no current flows through the relay, and the sender's signals do not therefore affect his apparatus.

The path of the compensation current is from the positive pole of the battery to *C* along *C F* through the rheostat back to the negative pole of the battery. The line current flows from the positive pole of the battery through *C E* along the line to *G*. At this point the current divides, one portion passing through the relay in the direction *U* to *D* and along *K H* to *H*, and the other along *G H* to *H*, where the two parts reunite and pass through the back contact of the key to earth and thence to the negative pole of the *A* battery. The mark is produced by that portion of the current which passes through the relay. The rheostat circuit may in this instance be regarded as a high resistance shunt across *K H*, which therefore somewhat reduces the resistance between *K* and *H*. The main path of the received current is along *G H* with the relay and the joint resistance between *K* and *H* placed in series across *G H*. The current through the relay is therefore rather less than half of that arriving at *G*.

If the key at *B* is depressed instead of that at *A* the current divides equally between *H G* and *H K*, so producing equal potentials at *G* and *K*. The line current passes to *E*, along *E C* and the path in parallel with it (*EFC*), to earth, and so back to the battery at *B*. The path in parallel with *E C* is the relay in series with the combined resistances of *C F* and *R*.

When both keys are simultaneously depressed the batteries oppose each other in the line and the current at *A* flows along *C F*, with *C E* and the relay joined across it, through the rheostat to the negative pole of the battery. The portion of the current taking the path of *C E* and the relay produces the mark. Similarly the mark at *B* is produced by that portion of the current from *B*'s battery which takes the path through *G H* and the relay.

INTERMEDIATE POSITION OF THE KEY.

The intermediate position of a key during the continuous depression of the distant key throws the rheostat into the line circuit and the received mark is made by the current flowing through the relay, shunted by *C E* and *C F* in series, and through the rheostat to earth. The received mark is therefore not interfered with. At the sending end the balance is upset and the relay tends to mark, but the current flowing through it is much less than in any of the cases considered. The position of the key when touching neither front nor back stop is only of momentary duration and does not produce any serious effect upon the working of the arrangement.

RESISTANCE OF THE ARMS OR DUPLEX COILS.

In the arrangement considered the resistances *C E* and *C F* have been given equal values, but this is not essential. Equality of potentials will be produced at *E* and *F* if the product of the resistances of *C E* and the rheostat is equal to the product of those of *C F* and the line circuit (including distant apparatus). This fact may readily be proved by a consideration of the principle of the Wheatstone Bridge (*q.v.*).

If *C F* and *R* are greatly increased in value in comparison with *C E* and the line circuit the value of the current sent to line is considerably increased, whilst the proportion of the current received passing through the relay when receiving is correspondingly reduced. The best values can, in any particular case, be mathematically determined, but it will suffice to say that under the conditions in which the system is employed by the Post Office the values are fixed at 3000$^{\omega}$ each.

DOUBLE CURRENT WORKING.

As in the differential system, the batteries are arranged to combine when both keys are at rest or both are depressed, and the increased current in the line circuit produces a difference of potential across the terminals of the receiving apparatus. When one key is depressed the batteries oppose each other in the line circuit, and the mark is made at each end by the home battery. To effect the combination of the currents in the line circuit and to obtain the correct direction through the receiving apparatus the battery and relay connections at the down station are reversed. The connections of the Post Office Bridge duplex are depicted in skeleton in Figs. 223 and 224. The paths of the currents have been distinctively indicated by arrowheads in order to make the somewhat complicated derived circuits easy to follow.

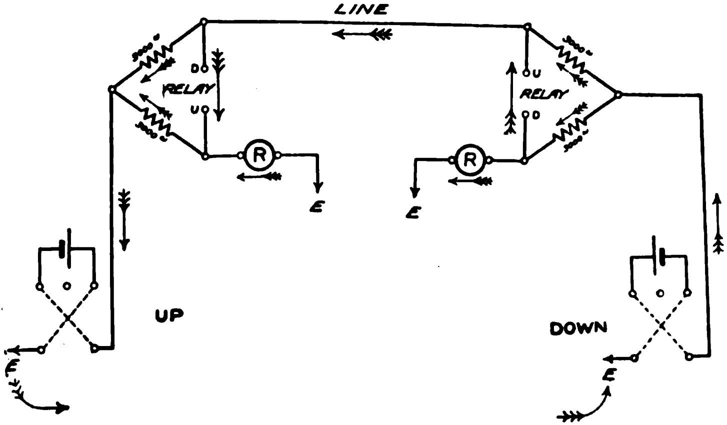

FIG. 223.—Skeleton connections of Bridge duplex, keys at rest.

BOTH KEYS AT REST.

The circuit is first balanced with the aid of the galvanometer placed in series with the receiving apparatus, resistance equal to that of the line and distant receiving apparatus being inserted in the rheostat so that with the distant battery switch in the earthing position the galvanometer is undeflected and is likewise unaffected by the sending key. As in the differential duplex, the switch replaces the battery by a resistance equal in amount to the internal resistance of the battery. Considering each station separately, but with the distant battery switch to earth, it will be recognized that the current circulating through the line duplex coil and the line is equal to the current flowing through the compensation circuit duplex coil and the rheostat. There is therefore no difference of potential across the receiving apparatus—a condition which has been secured by actual balancing.

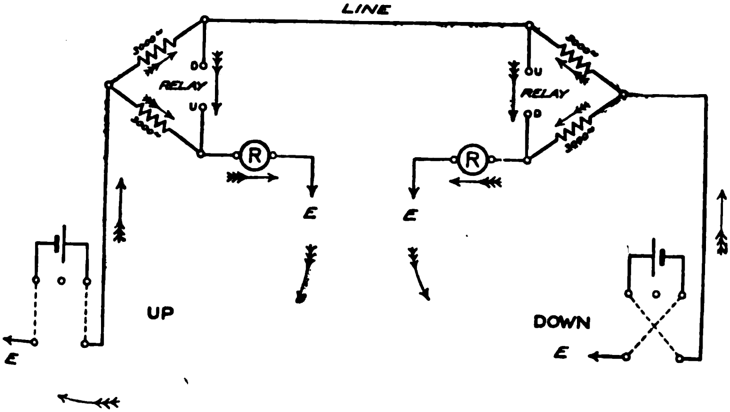

FIG. 224.—Skeleton connections of Bridge duplex, up key depressed.

Considering now the conditions which result when the batteries at both ends are joined up and with both keys at rest, it will be observed that the up and down batteries combine in the line circuit, thus producing twice as much current in that circuit as either battery acting alone. The path of this increased current is from the positive pole of the up battery via earth to the down battery with which it joins, through the divided circuit formed by the line duplex coil with the compensation circuit duplex coil and relay, along the line to the up station, where it again divides, part passing through the line duplex coil and part through the relay and compensation circuit duplex coil, which together form a shunt across the line duplex coil back through the key to the negative pole of the up battery. The relay tongues at each end are therefore held over to the spacing side by the proportion of the increased current, due to the combination of the two batteries, which is shunted through the relay and compensation duplex coil in each case.

The paths of the currents are shown by the arrow heads in Fig. 223. It will be observed that the currents at each end due to each battery acting separately are balanced, and the current in the relay at each end is therefore produced solely by the current received from the distant office.

It will therefore be recognized that the sender's current does not encounter the inductance of the sender's receiving apparatus since his current is accurately balanced, and the current producing the effect is that received from the distant station.

ONE KEY DEPRESSED.

With one key only depressed the batteries oppose each other in the line circuit and the relays at each end are energized by the home current derived from the ends of the compensation circuit duplex coil. This condition is indicated in Fig. 224, where the up key is shown depressed. The line circuit being stopped, the path of current is, at the up station, from the positive pole of the battery through the key, to the duplex coils, at which point it splits, part passing through the compensation circuit duplex coil, and the remainder through the line duplex coil and relay in the direction *D* to *U*, to re-unite with the portion flowing through the compensation circuit coil through the rheostat to the key and thence to the negative pole of the battery.

At the down station a similar circuit is formed, the relay marking with the current shunted from the compensation circuit duplex coil by the parallel circuit composed of the line duplex coil and the relay.

BOTH KEYS DEPRESSED.

When both keys are depressed the paths and values of the currents are identical with those of Fig. 223, but in this case the direction of the current is everywhere reversed, and consequently both relays register a mark.

INTERMEDIATE POSITION OF KEYS.

Double current keys with adjustable contacts are employed, and the effect of the momentary short circuit is immaterial. But when the transmitter is running there is, of course, a definite interval of break. Let the down station be sending a spacing current whilst the interval of break results from the up station changing from transmission of a marking to a spacing current. The break leaves the value of the spacing current in the up relay practically unaffected, but greatly reduces the value of the marking current through the down relay, since the down current now traverses the up rheostat and relay, the latter being shunted by both the duplex coils in series.

COMPENSATION CIRCUIT AND BALANCING.

The differential galvanometer (coils in series) is placed in series with the receiver, and balancing is effected precisely as described in the case of a differential duplex, and is preferably carried out with the distant battery switch to earth.

The behaviour of the condensers and the timing or discharging resistances is precisely as in the differential system. The values of the line charges in the various positions of the keys are likewise identical with the corresponding conditions of Fig. 144.

GENERAL ARRANGEMENTS.

The duplex resistance coils are contained in a box furnished with three terminals and two plugs. A signalling condenser is connected across each coil, but for economy of space the two condensers are placed in a single box provided with three terminals (Fig. 225). A shunted condenser is connected in series with the receiver and galvanometer across the ends of the duplex resistance coils. A triple condenser is usually required in the compensation circuit (Fig. 224 A).

THE SIGNALLING CONDENSERS.

The capacity of the circuit must always be satisfied before the current can attain its full value at the receiving end of the circuit. The time taken for the current to rise to its full value has already been explained to be quite independent of the E.M.F. employed. But the time taken for the current in the circuit to rise to *any given value* may be reduced by increasing the value of the E.M.F. applied. Therefore a signal may be produced by 100 volts in (very roughly) half the time that would be required by 50 volts, or in one quarter the time required by 25 volts—always provided that the maximum value of the current with the lowest E.M.F. was itself adequate.

In the bridge duplex the addition of the signalling condensers produces the advantages which would accrue from the use of nearly twice the battery power, but without its attendant disadvantages. The signalling condenser across the duplex resistance coil connected to line acts as a short circuit until it is fully charged. During this time the full E.M.F. of the battery is applied between the ends of the line, so producing a heavy rush of current into the line. When the condenser is charged, the current traverses the 3000^{ω} coil before reaching the line, and the E.M.F. applied to the ends of the line is less than the full E.M.F. of the battery by the amount taken up in overcoming the resistance of the coil. If the resistance of the receiving apparatus and the line is 3000^{ω} the E.M.F. lost in the duplex coil would be one-half the E.M.F. of the battery.

Since a signalling condenser is applied to the line circuit it will be obvious that in order to maintain a balance an exactly similar condenser must be applied to the compensation circuit.

Upon reversal of the current the discharge of the condensers combine with the battery which has been reversed, and the E.M.F. applied to the circuit is that of the battery *plus* the difference of potential due to the charge in the condensers. Until the condensers are discharged and charged in the reverse direction the duplex coils may be regarded as being short-circuited. During the discharge of the condenser its "suck out" action is of enormous value in hastening the discharge of the line. The capacity of the condensers determines the duration of the effect, and the best value for any given circuit is obtained when the quantity of electricity in the condenser is equivalent to the charge upon the cable. If the capacity employed is excessive the current will rise to too large a value, and there will then be a reverse discharge of the line immediately the current is reduced to its normal value.

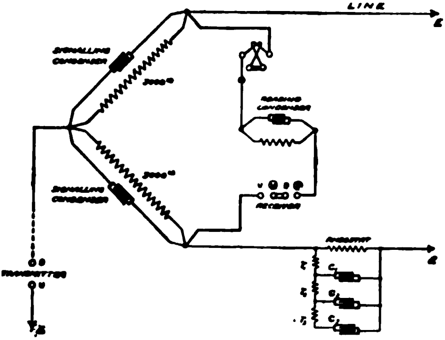

FIG. 224A. Bridge duplex, arrangement of condensers.

SUMMARY OF THE ACTION OF THE SIGNALLING CONDENSERS.

To summarize the action of the condensers; they act as short-circuits upon the duplex coils during charging. The reduction in the resistance of the circuit provides a correspondingly heavier flow of current which charges the cable more rapidly than the normal current. The condensers are adjusted so that the heavy current only lasts until the cable contains the same quantity of electricity which the normal current would supply. When the rush of current is over, the normal current at once produces its effect at the distant end because the cable is fully charged. Upon reversal of the current the condensers act with the battery, and a heavy rush of current in the reverse direction results, so more rapidly discharging and recharging the line in the reverse direction.

READING CONDENSER.

The shunted or "reading" condenser consists of a $14{,}000^{\omega}$ three-coil resistance box (2000^{ω}, 4000^{ω} and 8000^{ω} coils), and an adjustable condenser of the 7¼ or 11½ m.f. type. The action of this condenser is entirely similar to that described upon page 351, but its importance is, if possible, even greater. A small portion of the first part of every received signal is lost by reason of the short-circuiting effect of the home signalling condensers. When the up key is released the conditions of Fig. 224 are changed into those of Fig. 223. Now the first portion of the negative current flows along the line to the down station, through the signalling condenser across the line duplex coil and through the battery to earth. In Hughes working this effect is of such serious consequence that signalling condensers cannot be employed. The reading condenser certainly mitigates this evil, and in Wheatstone working the rapid charging of the line, which is secured by the use of the signalling condensers, more than compensates for the deleterious effect upon the received signals.

CONNECTIONS.

The full connections of a Bridge Wheatstone duplex are shown in Fig. 225. The duplex switch is of the 9-terminal 2-position type used in quadruplex circuits and in the duplex position makes the connections shown in skeleton in the previous diagrams.

When the switch is turned to simplex, the line duplex resistance coil is disconnected from line and the left side of the galvanometer is connected to *D* of the transmitter. An incoming current therefore passes from the line, through the galvanometer, *D* to *K* of the transmitter, and through the key, the central terminal of which is connected through the switch to the reading condenser, and thence through the receiver and rheostat, which should be placed at zero, to earth. The reading condenser is thus available for simplex working. As *U* of transmitter and the left terminal of the key are earthed currents are sent out via *D* of the transmitter and the galvanometer to line.

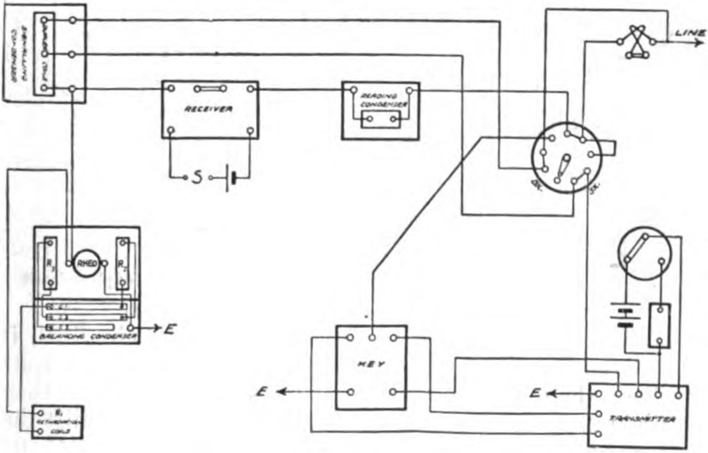

Fig. 225.—Connection of Bridge duplex.

At a down station it is necessary—

(i) To reverse the connections on the upper terminals of the galvanometer.

(ii) To reverse the connections of the receiver, and

(iii) To reverse the battery connections on *Z* and *C* of the transmitter.

CALCULATION OF THE CURRENT IN EACH PART OF THE CIRCUIT.

The calculation of the values of the current in the various branches of the bridge duplex circuit is quite simple, but it involves some tedious arithmetical work.

The resistance of the battery is assumed to be nothing, and that of the shunted condenser and relay 2400ω. The simplest method of dealing with the calculations is to consider each end separately, and to assume that the distant battery is for the time short-circuited. When these calculations are completed it is only necessary to add the two results found for each part of the circuit.

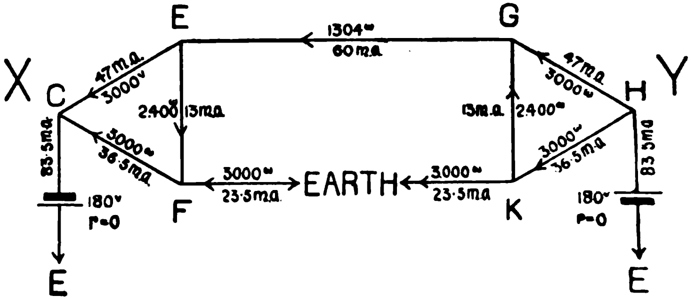

FIG. 226.—Paths and values of the currents in each part of a Bridge duplex circuit with both keys at rest.

Assuming that the battery at *X* is short-circuited, it will be seen (Fig. 226) that a current due to 180 volts flows along *H G* and the line to *E*. The current then divides, one part passing direct to earth (at *C*), whilst the other passes through the relay and then through *F C* and the *F*-Earth path in parallel. The circuit is in fact as shown in skeleton in Fig. 227.

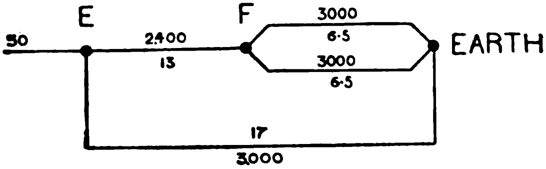

FIG. 227.—Skeleton connections with one key at rest.

$$\text{Resistance from } E = \frac{(2400 + 1500) \times 3000}{(2400 + 1500) + 3000} = 1696^{\omega}$$

Since *G* and *K* are at equal potentials with respect to the battery at *Y* (the *X* battery being regarded as short-circuited), the total resistance of the line circuit for the battery at *Y*

$$= 3000^{\omega} + 1304^{\omega} + 1696^{\omega}$$

$$\therefore \text{ Current} = \frac{180^{v}}{6000^{\omega}} = 30 \text{ m.a.}$$

As the resistance of the paths *EF*-Earth and the lower path (Fig. 227) are respectively 3900^{ω} and 3000^{ω} the currents are in inverse proportion to those resistances; *i. e.* they are 13 m.a. and 17 m.a. respectively. The 13 m.a., however, divides into two equal parts at *F* as shown.

Imagining the battery at *Y* short-circuited, and that at *X* acting, the current through *CF* and the compensation circuit is :—

$$\frac{180^{v}}{3000+3000} = 30\text{m.a.}$$

As the circuit is balanced an equal current flows along the line circuit and produces values at *Y* similar to those already found for *X*.

When both batteries are in action the currents are the sums of those previously found, viz. :—

In *CE* 17 (from *Y*) + 30 (from *X*) = 47 m.a.
„ *CF* 6·5 (from *Y*) + 30 (from *X*) = 36·5 m.a.
„ *F*-Earth 30 (from *X*) − 6·5 (from *Y*) = 23·5 m.a.
„ *EF* 13 (from *Y*) = 13 m.a.

Through the battery 17 from *EC* due to *Y*
6·5 „ *FC* „ „ „
30 line current from *X*
30 compensation current from *X*

= 83·5 m.a.

The only point which calls for comment is in regard to the current in *F*-Earth. The direction of the compensation is opposite to that of the received current, and its value is therefore equal to the difference between them. The currents at the *Y* end may be obtained similarly, and are as shown in Fig. 226.

When one key is at rest whilst the other is depressed the conditions at each end are as shown in Fig. 228.

$$\text{Resistance} = \frac{(3000 + 2400) \times 3000}{(3000 + 2400) + 3000} + 3000$$
$$= 4929^{\omega} \text{ approx.}$$

$$\text{Total current} = \frac{180}{4929} = 36 \text{ m.a. approx.}$$

Current through relay and upper path

$$= \frac{3000}{3000 + 5400} \text{ of } 36 \text{ m.a.}$$
$$= 13 \text{ m.a. as before.}$$

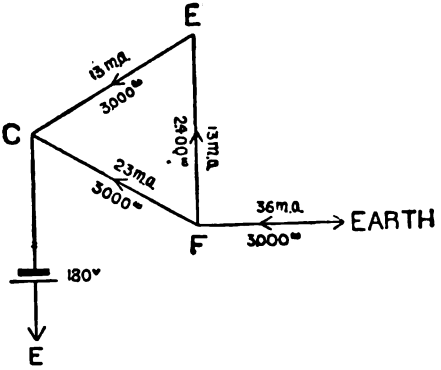

Fig. 228.—Paths and values of the currents in each path with one key depressed.

Calculation of Battery Power.

If it is required to ascertain what power must be employed to obtain a certain current through the receiver with a line of given resistance, it is first necessary to calculate the value of the resistance required to balance the circuit. This may be obtained from the following formula :—

$$R = \sqrt{\left\{\frac{a^2 S}{2a + S} + \frac{a^2 + aS}{2a + S} L + \frac{L^2}{4}\right\}} + \frac{L}{2}$$

where R = resistance required in the rheostat
a = resistance of each duplex coil 3000^{ω}
S = resistance of receiver and in shunted condenser
L = resistance of the line.

For $S = 400^{\omega}$ the formula becomes :—

$$R = \sqrt{\left(562500 + 1596\,L + \frac{L^2}{4}\right)} + \frac{L}{2}$$

and for $S = 2400^{\omega}$

$$R = \sqrt{\left(2571000 + 1929\,L + \frac{L^2}{4}\right)} + \frac{L}{2}$$

In the case illustrated $L = 1304$ and $S = 2400^{\omega}$

$$\therefore R = \sqrt{2571000 + 2515000 + 425000} + \frac{L}{2}$$

$$= 2347 + \frac{1304}{2} = 2999^{\omega}$$

which is very approximately correct.

Assuming that 13 m.a. is required through the relay and that No. 1. cells are used the number of cells required is found as follow :—

Referring to Fig. 228.

If the current through the receiver is 13 m.a. the current in the lower duplex coil is clearly $\frac{5400}{3000} \times 13 = 23{\cdot}4$ m.a.

$\therefore$ total current $= 36{\cdot}4$ m.a.

Joint resistance of 3000^{ω} and $5400^{\omega} = 1929^{\omega}$

Total external resistance $= 3000 + 1929^{\omega}$
$= 4929^{\omega}$

$$\text{Number of cells required} = \frac{4929}{\dfrac{1{\cdot}0}{{\cdot}0364} - 2} = 194$$

With the secondary cells the calculation is even simpler.

Resistance in battery lead $= 300$
Total resistance $= 4929 + 300 = 5229^{\omega}$
Current required $= 36{\cdot}4$ m.a.
E.M.F. required $= 5229 \times {\cdot}0364 = 190^{v}$

POWER EMPLOYED.

The minimum power required is 100 volts. No. 1 cells are used.

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CHAPTER XII

THE WHEATSTONE A.B.C., STELJES RECORDER, AND REBESI TYPEWRITING TELEGRAPH.

THE chief advantage of the A.B.C., which is a step-by-step telegraph, lies in simplicity of operating. It is used on many private wires, but most minor telegraph circuits are now worked by telephone (then termed phonogram circuits), telephone call office facilities being also provided. The A.B.C. is costly to provide and to maintain, but only one wire is required against the two of a telephone circuit.

GENERAL PRINCIPLE.

The electrical energy required for the operation of the instrument is obtained by revolving the handle of the sending instrument or "communicator" as it is termed. This operation causes the armature of a generator or magneto-electric machine to revolve and so generate an alternating E.M.F. The position of the key which is depressed determines the number of current waves sent out, and thus controls the position of the pointer at the distant end of the circuit.

THE COMBINED INDICATOR AND BELL.

The indicator bears a considerable resemblance to the P.O. standard relay in the general arrangement of its electrical and magnetic parts. Two soft iron armatures, rendered magnetic by induction from a curved permanent magnet of a horseshoe type, are placed between the four poles of the electromagnet. The axle carrying the armatures also bears an arm upon which is pivoted an escape wheel of the form illustrated in Fig. 229. The movement of this arm is limited by the stop-pins, P_1 and P_2 shown in Fig. 230. When an alternating current is passed through the coils of the instrument the arm oscillates between P_1 and P_2, and in so doing causes the escape wheel to revolve. In Figs. 229 and 230 the arm is shown in its

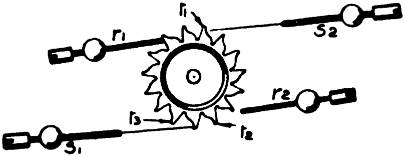

FIG. 229.—Escape wheel.

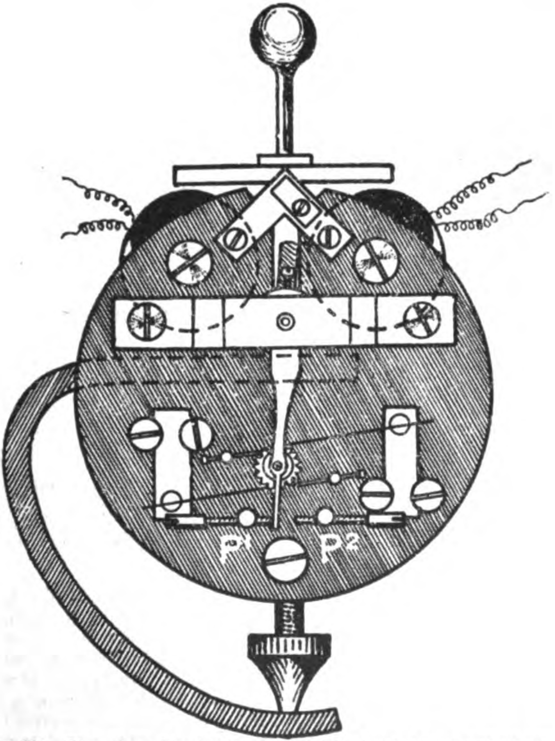

FIG. 230.—Plan of combined indicator and bell showing escape wheel arm.

left-hand position, so that a motion to the right therefore twists the escape wheel round to the extent of half a tooth.*

The primary object of the stop-pins P_1 and P_2 (Fig. 230) is to save the escapement wheel from the shocks which would result from its continual impacts upon r_1 and r_2. It is, however, found that the increased wear due to this cause is very slight, and in some forms of apparatus P_1 and P_2 are omitted.

In the latest pattern the pallet springs, s_1 s_2, the pins r_1 r_2 and the stop-pins P_1 P_2 have all been replaced by a pair of agate discs mounted as indicated in Fig. 231. These discs may be turned to expose fresh wearing surfaces when necessary.

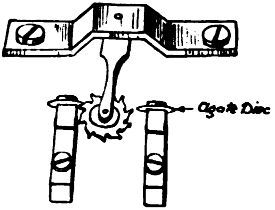

FIG. 231.—Escape wheel and agate discs.

The fifteen teeth of the escape wheel are slightly undercut to prevent the possibility of the pallet springs being jerked upwards by a sudden or "jerky" motion of the escape arm. In order to facilitate removal and adjustment these pallet springs are separately mounted upon removable brass blocks.

A complete revolution of the escape wheel needs thirty motions of the arm alternately right to left and left to right. These movements would be produced by sending fifteen complete alternations through the electromagnet. Each of the thirty positions of the escape wheel corresponds to a letter or character, and therefore the pointer, which is fixed to the escape wheel by means of a light steel axle, may be caused to stop opposite any predetermined letter or character by sending the requisite number of alternate positive and negative currents through the instrument. For example, the pointer will move from zero to *A* if one positive current is sent, whilst a positive followed by a negative current would cause it to move to *B*. The effect of each positive or negative current wave is clearly depicted in Fig. 232.

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* The tooth t_1, which is resting against the pallet spring s_2, remains stationary whilst the centre of the wheel moves over to the right. When this position is reached t_2 banks against the pin r_2 whilst s_1 has engaged with t_3. If the arm is now moved over to the left, the escape wheel again rotates in the same direction to the extent of half a tooth. It will therefore be seen that the escape wheel is rotated by the action of s_2 when the motion is from left to right, and by s_1 when in the reverse direction. The function of the pins r_1 and r_2 is to prevent the wheel from moving more than half a tooth at a time when the arm moves from side to side.

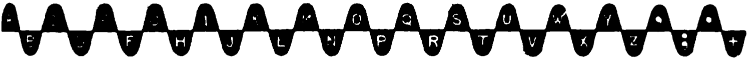

Fig. 232.—Currents and letters.

A mechanical method of putting the indicator pointer to zero is provided, so that, in the event of faults or interruption of a message by the receiving station, both offices may re-set their pointers to zero. This is accomplished by the small handle (Fig. 233) at the base of the indicator dial, which mechanically moves the escape wheel and pointer axle to right or left according to the direction in which the handle is moved.

The bell portion of the instrument, vide Figs. 230 and 233, now requires consideration. The polepieces of the electromagnets are extended in an upward direction, and above them are placed two soft iron armatures. The centres of these two armatures are mechanically and magnetically connected to the light permanent bar magnet, which polarizes both. The two ends of the upper * armature are South poles, and therefore the passage of a current through the instrument causes one end to be attracted whilst the other is repelled. When the current is reversed the armature moves in the opposite direction. Since the ends of the lower armature are of opposite polarity to those of the upper one their tendency to motion is always in the same direction as that of the upper armature. Attached to the permanent magnet is an arm carrying a bell hammer normally resting upon one of the two bells between which it is placed. It will therefore be obvious that the alternating currents which actuate the indicator pointer will also cause the hammer to play between the two bells, thus giving a sufficiently loud ring to call attention to the circuit. A switch is provided which clamps the hammer of the bell when turned to the "off" position during the transmission of messages.

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* Seen at the bottom in the figure.

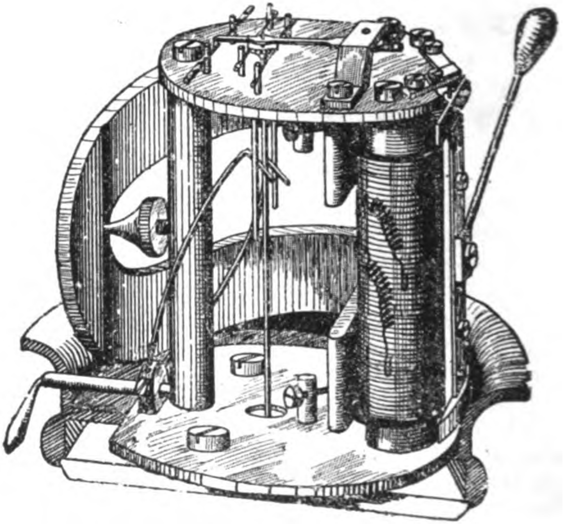

FIG. 233.—Perspective sketch of the arrangement of a combined indicator and bell.

THE GENERATOR.

It has previously been stated that an E.M.F. is generated whenever a conductor cuts a line of force. The value of this E.M.F. is directly porportional to the number of lines of force cutting a conductor in a given time. In order to generate any considerable value of E.M.F. it is necessary that a large number of lines of force should be cut at a considerable speed by a number of suitably arranged conductors. This result may be accomplished in quite a large variety of ways, but in the present volume it is only necessary to give a detailed explanation of one of them.

The type of machine chosen is that used so extensively in telephony under the title "generator," and also used in the

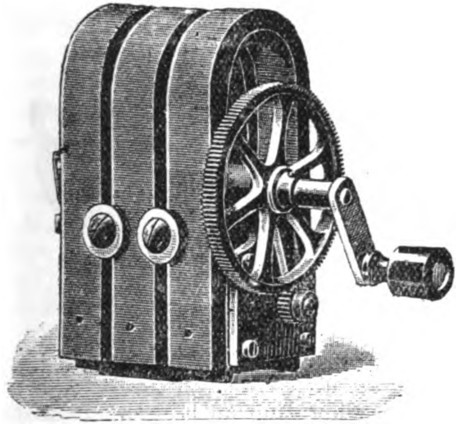

FIG. 234.—View of a magneto generator.

Wheatstone A.B.C. and Steljes instruments. In reality, it is the Siemens magneto-electric machine of 1857, made to a small scale and minus the commutator.

The generator usually consists of three permanent magnets, whose poles of like sign are united by two hollowed soft iron polepieces, between which is placed a revolving armature of soft iron wound with a suitable number of turns of fine silk-covered copper wire. The instrument as a whole is illustrated in Fig. 234, whilst constructional sketches are given in Figs. 234 and 235. The armature is of the well-known H-form, and the coil is wound upon the central web. When

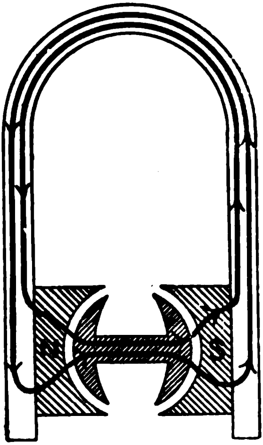

FIG. 235.—Magnetic circuit of generator.

the armature occupies the position shown in Fig. 235, the lines of force pass through the central web in the general direction shown by the two heavy lines. When the position of the armature is changed with respect to the magnet the position of the lines with respect to the coil of wire is altered, thereby generating an E.M.F. It should also be noted that the magnetic field passing through the coil is intense, since the magnetic circuit is almost wholly of iron, the two small gaps of air between the armature and the polepieces being only of sufficient width to provide a working clearance.

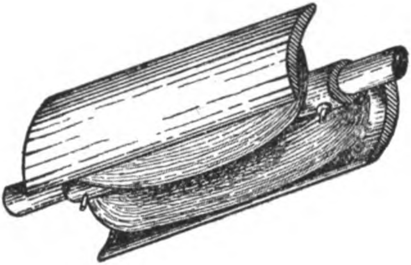

Fig. 236.—Armature of generator.

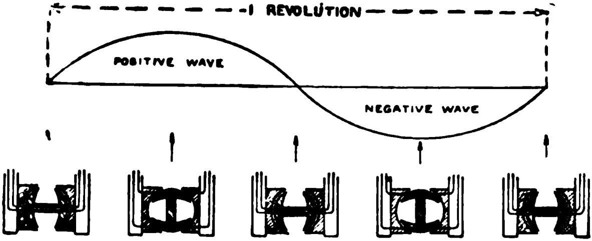

Fig. 237.—Illustrating current waves sent out by generator.

The value of the E.M.F. at every instant during a revolution, together with the position of the armature at each quarter of a revolution, is shown in Fig. 237. Imagine that the armature is revolving at a uniform speed, and that, to commence, it occupies the position marked "start." Here, the whole of the lines of force pass through the coil along the web, and none through the curved portions of the armature. When the armature has turned through a quarter of a revolution there will then be no lines of force passing through the coil. At this point the value of the E.M.F. generated is at a maximum, whilst it steadily decreases in value during the succeeding quarter of a revolution. Up to the third quarter of a revolution the number of lines flowing through the coil steadily decreases in value until the maximum E.M.F. in the reverse direction is reached. From this point to the end of the revolution the negative E.M.F. gradually sinks from its maximum value to zero, when the armature occupies the same position as at the start.

THE COMMUNICATOR.

It has been shown how the pointer may be caused to travel to any one of the thirty characters by meting out a suitable number of current impulses alternately varying in direction. It is now necessary to consider the mechanism of the communicator by which this object is effected.

The dial, furnished with a pointer, is divided into thirty divisions corresponding with those of the indicator. A key is placed opposite each character, and messages are sent by revolving the handle and depressing the keys in the order in which the letters occur in the words to be signalled. The completion of a word is indicated by pausing at zero. The pointer is arrested at the point where the key is depressed, and is released immediately a second key is put down. This depression of the second key also restores the first to the normal position.

ARRANGEMENT OF THE KEYS AND ENDLESS CHAIN.

The necessity for pivoting the keys is avoided by an arrangement which will readily be apprehended from a consideration of Fig. 238. The lower end of each key passes through a radial slot in the key plate. The upper end, carrying the finger-plate *K*, projects above the slot, and is kept in position by the circular brass ring *B*, which is screwed down above all the keys. Since the fitting at the angle is made rather loose the key is able to rock, thus producing the effect of a hinged joint in a singularly neat manner.

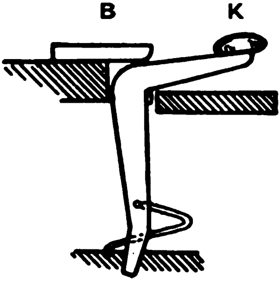

Fig. 238.—Key.

The lower ends of all the keys rest upon an endless chain which is carried upon a series of pulleys (Fig. 239). The length of the chain is such that one key only may be depressed at any one time. The depression of a second key tightens the chain at the point where the first key is depressed, so thrusting the first back to the normal position. In order to provide a margin of adjustment two extra

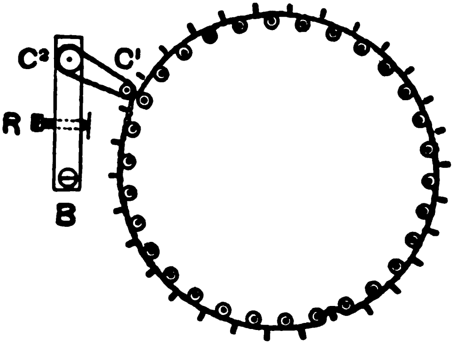

Fig. 239.—Endless chain and its adjustments.

pulleys C_1 and C_2 are employed, so that by turning the screw *R*, which is fixed upon the brass block movable at *B*, the requisite tightening or slackening of the chain may readily be effected.

Operation of Contact Maker and Pawl Arm.

The exact connection between the number of currents sent out, the pointer, and the armature of the generator remains to be dealt with. In Fig. 240 some liberties have been taken with the actual details of the construction of the instrument, and it is especially desired that this fact should be borne in mind. The main axle to which the handle is attached is correctly shown, but the remainder of the apparatus has been turned through an angle of 90°.

The handle carries the armature driving wheel *N* and the bevel wheel *A*, which causes the corresponding wheel *B* with the spur wheel *C* to revolve continuously. Above this is an arm fitted with a pawl which engages the spur wheel and so imparts motion to the pointer carried upon the axle *G*. Between *F* and the pawl a friction-tight contact arm *K* is fitted. This arm tends to revolve with the spur wheel, but is prevented from doing so by a stop-pin.

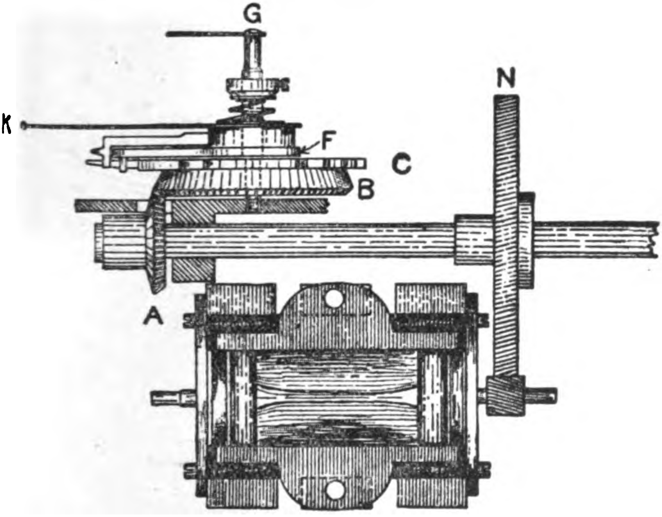

FIG. 240.—General arrangement of communicator.

Referring now to Fig. 241, which gives a plan of the important parts of the spur wheel, etc., it will be seen that when all the keys are raised the pawl engages with one of the teeth upon the spur wheel, and so causes the arm *M* to revolve. The contact arm *K* is fixed friction-tight with the pawl arm *M*, and, therefore, whilst *M* revolves, *K* moves upwards, thus establishing a connection between the pivoted lever *T* and the uninsulated side of the contact arm *K*, and breaking that which normally exists between *T* and *S*. Since fifteen complete alternations must be sent out during one revolution of the pointer the armature of the generator must make fifteen revolutions whilst the pointer makes one.

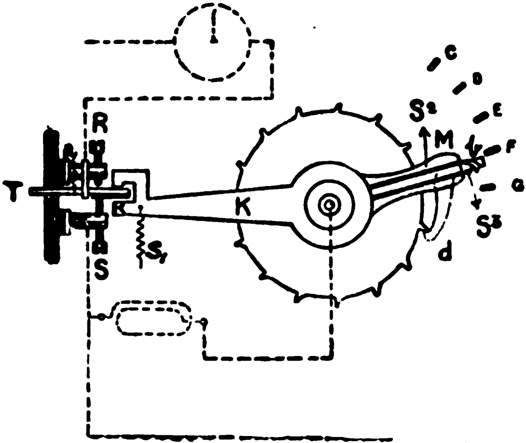

FIG. 241.—Spur wheel and contact maker.

The function of the spur wheel and pawl is to disconnect mechanically the handle from the pointer immediately the latter reaches a depressed key. The contact arm then electrically disconnects the armature, so preventing more than the correct number of alternations from being sent out.

Immediately the extremity of the pawl *b* meets a depressed key, *d* moves outwards, thus disconnecting *M* from the spur wheel. The spring S_1 upon the contact arm immediately restores the contacts to their normal position. If the zero key were depressed *M* would stop opposite zero whilst the spur wheel continued to rotate. The depression of, say, the *A* key and the consequent rising of the zero key would permit the springs S_2 and S_3 to restore the pawl to its normal position, when it would again engage with the spur wheel and move forward to *A*. In doing this *K* would move with *M*, so joining up the armature. Immediately *M* reached *A* the pawl would again disengage, and *K* would restore the contacts to the normal, so disconnecting the armature. If the *D* key were now depressed the pawl arm *M* would move from *A* to *D*, during which time *K* would join up the armature.

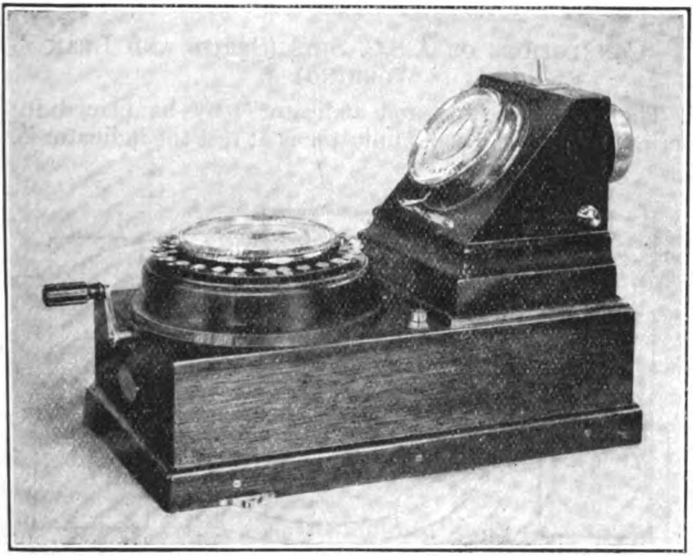

FIG. 242.—View of A.B.C set

The spur wheel is provided with 15 teeth, and is permanently geared to the armature. The distance between each tooth therefore corresponds to one complete revolution of the armature. It is essential that the armature should always be in the correct position with respect to the pole-pieces when the contact arm *K* joins it up. Were this not assured two positive or two negative currents might be sent out as the last current to signal a particular letter, and the first current for the next letter. The spur wheel and pawl provide that the armature is in exactly the same position when again connected to line as it was when the last current was sent.

It may be stated that upon circuits with more than two offices the necessity for attending to the instrument whenever the needle moves is obviated by the use of a system of calling, in which the various calling signals are recognizable by sound. For example *D*, zero, gives a sound similar to the letter "*A*" in Morse.

CONNECTIONS OF A.B.C. SETS (SERIES AND LEAK WORKING).

The communicator and indicator may be placed in series. When the communicator is at rest the indicator is connected between line and earth, or between the up and down lines by the contact arm.

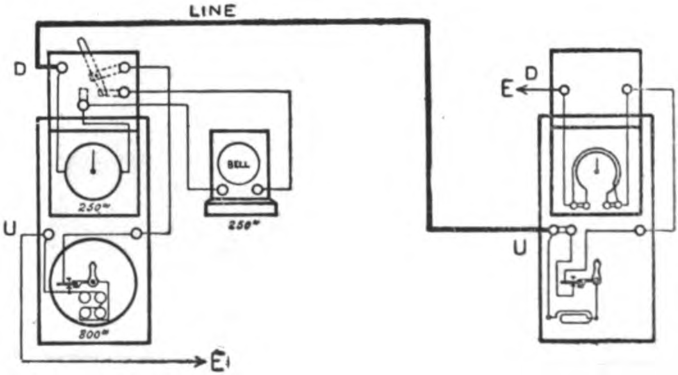

FIG. 243.—A.B.C. circuit. The apparatus at the up office is of the old form.

A view of the A.B.C. apparatus as a whole is given in Fig. 242.

The connections of two A.B.C. sets upon one circuit are depicted in Fig. 243, the up set having a communicator, indicator, and bell of the old type, whilst at the down station is shown the new form of communicator and the combined indicator and bell. The path of the current is sufficiently obvious.

The standard method of working A.B.C. circuits is upon the leak method with condensers in series with the indicators to eliminate the effects of their inductance and also to cut out any leakage currents which may be present. An 8 m.f. condenser and a 4000ω resistance coil is placed in series with the indicator (coils in series), and the second terminal of the communicator is left disconnected so that the armature is joined to line only when currents are actually being sent out.[1]

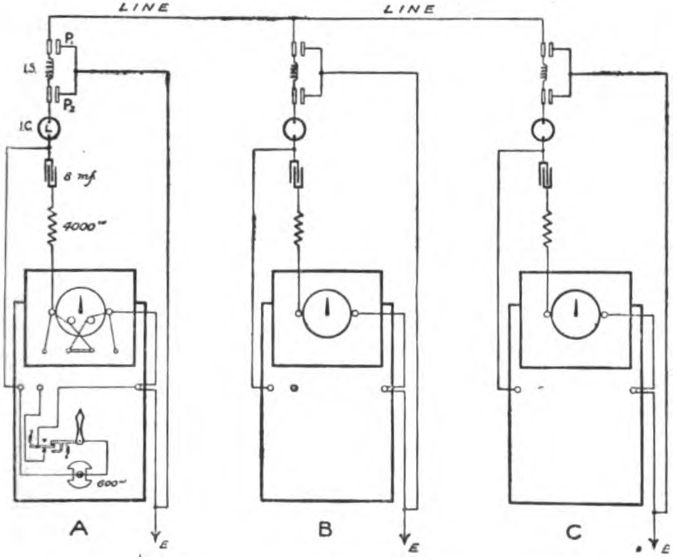

Fig. 244.—A.B.C. Circuit. Leak working. (P_1 and P_2 are lightning protectors and I.S. and I.C. are inductances in connection therewith.)

---

[1] The current C in a circuit containing resistance R, capacity K, and inductance L, due to an alternating E.M.F. of E volts with a periodicity of n complete alternations per second:—

$$C = \frac{E}{\sqrt{R^2 + \left(pL - \frac{1}{pK}\right)^2}} \text{ where } p = 2\pi n$$

The effects of inductance are eliminated when $pL = \frac{1}{pK}$ or $K = \frac{1}{p^2L}$.

Taking the average periodicity of the current on an A.B.C. circuit as 15 per second and the inductance as 14 henrys:—

$$K = \frac{1}{2^2 \times 3{\cdot}1416^2 \times 15 \times 14} = {\cdot}000008 \text{ approx} = 8 \text{ m.f.}$$

THE STELJES RECORDER.

The Steljes recorder which replaces the Wheatstone A.B.C. indicator prints the message in Roman characters upon a tape. It is used on many private wires where a record of the message is required.

The number of currents sent out by the communicator determines the position of the type wheel in a similar way to that in which the movement of the A.B.C. indicator needle is controlled. The printing electromagnet is placed in series with the escapement electromagnet, the armature of the former being permanently attracted whilst the pointer of the communicator is in motion and released only when the series of currents is ended. The moment the current ceases the tape is brought into contact with the inked type wheel, the character thereby recorded, and the tape moved forward. The type wheel is inked by means of a light wheel which normally rests upon and revolves with it.

TYPE WHEEL ESCAPEMENT.

The escapement electromagnet with its polarized armature is of the form which has long been familiar in telephone magneto bells. Its permanent magnet curves round from the yoke of the electromagnet to the centre of the soft iron armature, so making the two ends of like polarity. The pallet (Fig. 245) which engages with the escape wheels is fixed at right angles to this armature. Each wheel has fifteen equally spaced teeth placed so that the apices of the teeth of the one wheel are opposite the bases of the teeth of the other. The escape wheels are placed upon the same axle as the type wheel, which revolves when released by the pallet. When the armature moves, the pallet releases the tooth with which it is engaged, and thus allows the axle to turn until it engages with the tooth of the other escape wheel, *i. e.* the axle moves one-thirtieth of a revolution. In order therefore to bring any letter upon the type wheel directly above the paper, it is only necessary to send the requisite number of alternations through the electromagnet.

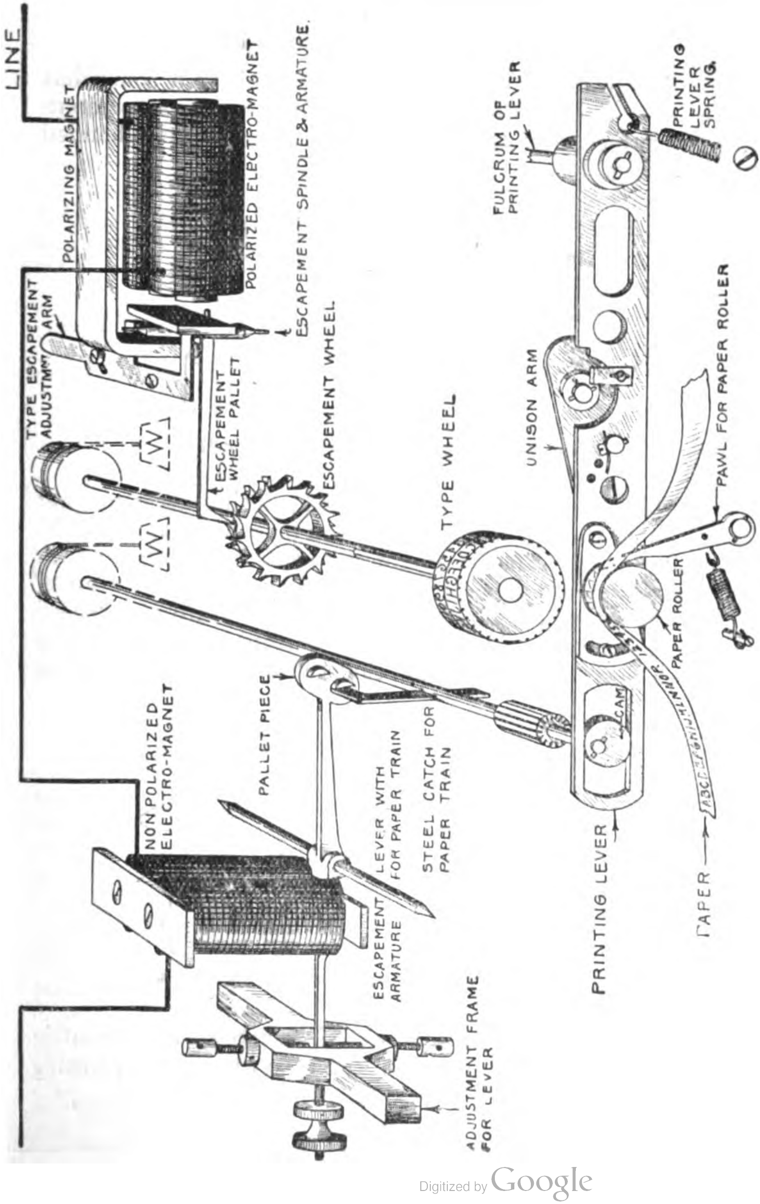

FIG. 245.—General figure illustrating principle and essential parts of recorder.

PRINTING ARRANGEMENTS.

The printing mechanism is operated by a somewhat heavier weight than that required for the escapement. The principle of the device will readily be apprehended from Fig. 245.

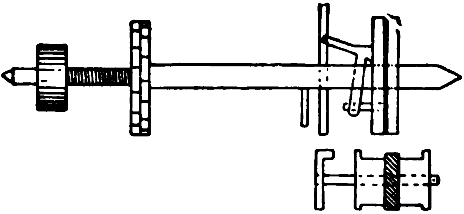

FIG. 246.—Type wheel in position for printing figures.

The armature of the nonpolarized printing electromagnet (seen on the left in Fig. 245) when attracted depresses the pallet piece. The lower stop now clears the catch which moves forward only to be arrested by the upper stop of the pallet piece. Immediately the armature is released by the cessation of the series of currents the upper stop rises clear of the catch, and thus the axle makes a complete revolution, being arrested by the lower stop. The eccentric cam raises the paper against the type wheel, thus printing the letter.

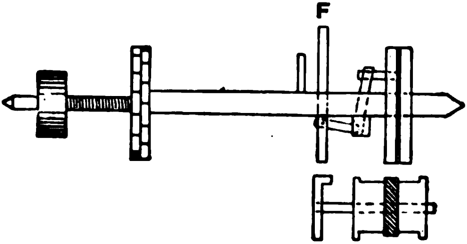

FIG. 247.—Type wheel in position for printing figures.

Figure Changing Cam.

Two type wheels mounted side by side upon the same axle are employed, the one bearing letters and the other figures and various other useful signs. The wheels are capable of lateral motion and either may be brought directly over the tape according to the position of the "figure changing cam." Two divisions exactly opposite to each other upon the communicator are marked respectively "letters" and "figures." At the corresponding points upon the type wheels blanks are left. When the printing lever raises the tape up to the type wheel at these positions no character is printed, but the radial pin *F* is struck, so moving the type wheels along the axle. In Fig. 246 the letter wheel is above the printing space upon the tape, whilst in Fig. 247 the figure wheel is similarly placed. When the upper end of *F* (Fig. 247) comes to its lowest position, the raising of the printing lever in response to the depression of the "figures" key causes the wheels to take up the position shown in Fig. 246. The change from figures to letters is made in a similar way, half a revolution (fifteen letters) of the communicator later. The type

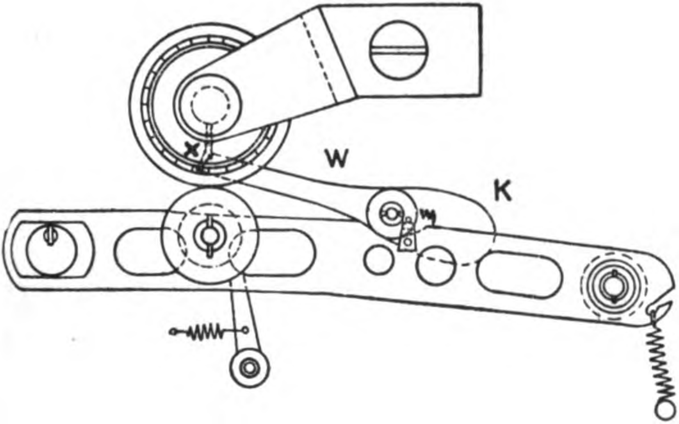

Fig. 248.—Printing lever and unison arm.

wheel which is not in use strikes upon a light forked steel spring which covers the two outer thirds of the paper.

GENERAL ARRANGEMENT AND SLIP FEEDING DEVICE.

Every time the printing lever (Fig. 245) is moved up against the type wheel the cam engages a lower tooth upon

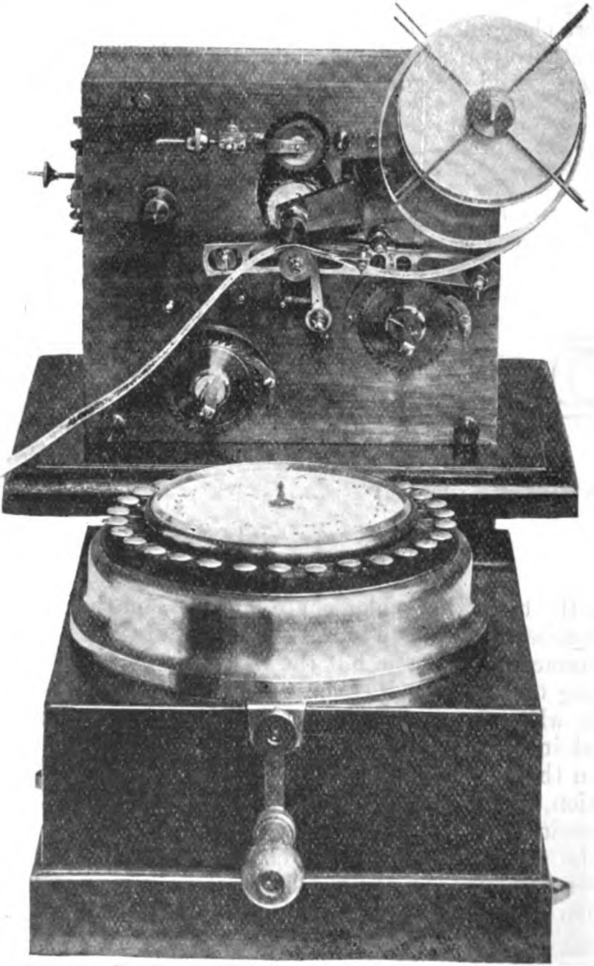

FIG. 249.—General view of Steljes apparatus.

the ratchet wheel, and the descent of the lever therefore feeds the slip forward to an extent equal to the space of one letter, so placing it in position for the printing of the next letter.

UNISON LEVER.

The unison device is exceptionally simple and effective. Upon the type wheel axle a radial arm *X* (Fig. 248) projects which engages with the end of the lever *W* when in its upper position. The lower part of the lever carries a pin W_1 which is struck by the printing lever every time a letter is printed, thus depressing the lever *W*. This lever is fixed friction-tight upon an axle which tends to move it to its highest position when the type wheel has moved through about three revolutions. If therefore the pointer of the communicator is allowed to make three complete revolutions without printing a letter the radial arm *X* is arrested and the type wheels stopped at zero. Immediately the type wheel stops the zero key is depressed and the communicator and the type wheels are therefore at zero,

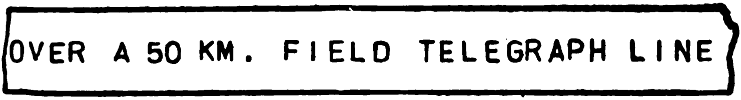
OVER A 50 KM. FIELD TELEGRAPH LINE

FIG. 250.—Specimen of printed message.

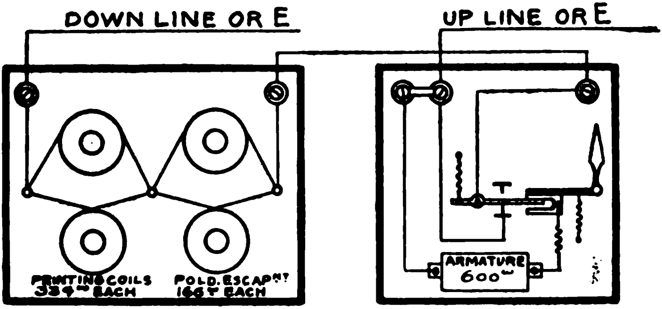

FIG. 251.—Connections for series working.

but the printing lever rises and puts the lever *W* back to its lower position as shown in Fig. 245. Both instruments are therefore at zero and the message may at once be signalled.

The general appearance of the apparatus is shown in Fig. 249, and a reproduction of a part of a message transmitted over a 50-kilometre field telegraph line established in Spain during manœuvres is shown in Fig. 250.

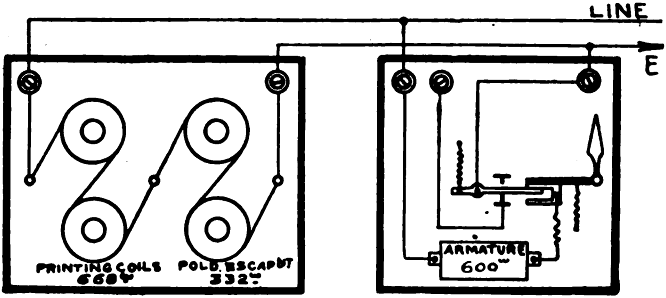

Fig. 252.—Connections for leak working.

A motor driven communicator of considerable power has also been produced—in fact, as many as one hundred recorders have been simultaneously worked from it.

Connections.

For ordinary, or series, working the recorder coils are joined up so as to give a resistance of 500ω, and the set as a whole is connected to line and earth in similar fashion to an ordinary A.B.C. set. When leak working is desired the windings of the coils are placed in series and a resistance of 1000ω is thereby obtained. The conditions will, however, be evident from consideration of Figs. 251 and 252.

THE REBESI TYPEWRITING TELEGRAPH

This is the invention of W. S. Steljes, and differs from the Steljes recorder in that a standard typewriter keyboard is used for sending, batteries are used in place of a generator for the line currents, a relay of special design is used to receive the line currents, the receivers are tape printing or column printing as required, and they have no train of wheels or weights or springs, all operations being obtained by the local current from the relay.

Fig. 253 and 254 are respectively a view and plan of the apparatus; on the left-hand side of the transmitter

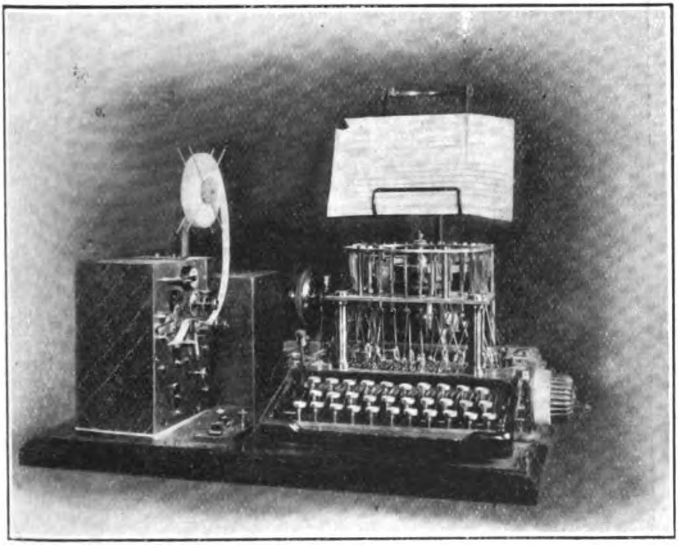

FIG. 253.—View of Rebesi tape printing telegraph.

is a pulley driven at about 300 revolutions per minute by a small motor, and in the centre is a commutator from which alternating currents are collected by the brushes and transmitted to the line. On the left-hand side of the keyboard a key is provided, the position of which is changed for sending and receiving. There is a locking device under the keyboard which holds one key down until the next key is depressed. The key levers, by an arrangement very similar to that in an ordinary typewriter, control the position of the spindles which engage with the revolving arm carried by the commutator, and the number of alternations sent to line by the commutator brushes depends upon the position in which the commutator is stopped by this arm. When used for column printing the transmitter is provided with an index showing the position of the typewheel at the receiving instrument. At the distant station the alternations are received by a single-coil relay having two polarized and one non-polarized armature (Figs. 255 and 256). In the diagram (Fig. 256) *a* represents the winding of the relay connected to the line, *b* the core, and *c*, *c* the pole pieces, *d*, *d* are the polarized armatures, *e*, *e* permanent magnets, *f* the non-polarized armature limited by

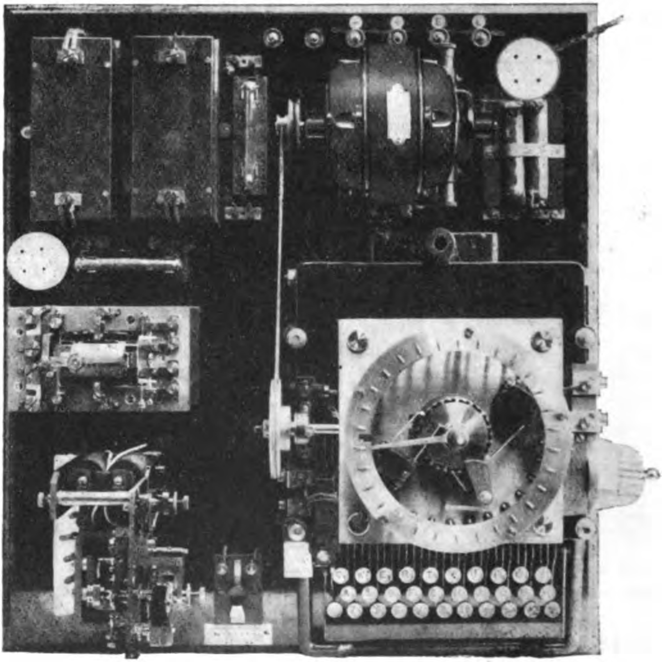

FIG. 254.—Plan view.

the adjustable insulated stop *m*. The alternating current impulses sent by the transmitter cause the polarized armatures of the relay to move synchronously, and when the transmitter is stopped at a letter to be printed, the prolonged impulse operates the non-polarized armature, but this armature is not operated by the short alternating current impulses. The armatures *d*, *d* are polarized by the permanent magnets *e*, *e*, and so arranged that the core, when magnetized by the line current, attracts one end of the armature and repels the other. Contacts are provided at the extremities of the armature, the number of contacts on each armature being arranged according to the number of local circuits. By this arrangement a number of local circuits can be worked by one relay only. It will be observed (Fig. 255) that the two polarized armatures with their four contact points provide the equivalent connections of a 6-terminal reversing key, and that therefore divided batteries are not required.

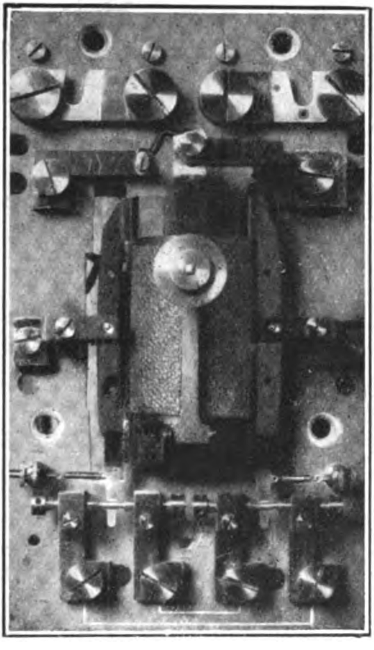

FIG. 255. Plan of relay.

The column printing machine is shown in Fig. 257. It will be seen that this machine is without the clockwork train of wheels, weight or spring driven, which was formerly used; in place of this arrangement, which had many disadvantages, the energy necessary for operating the typewheel and paper feed is considerably reduced, so that it can be obtained from the local battery controlled by the relay. The shaft on which the typewheel is mounted is divided, the two portions being coupled by means of a spring which permits relative movement between the parts and reduces the initial friction and

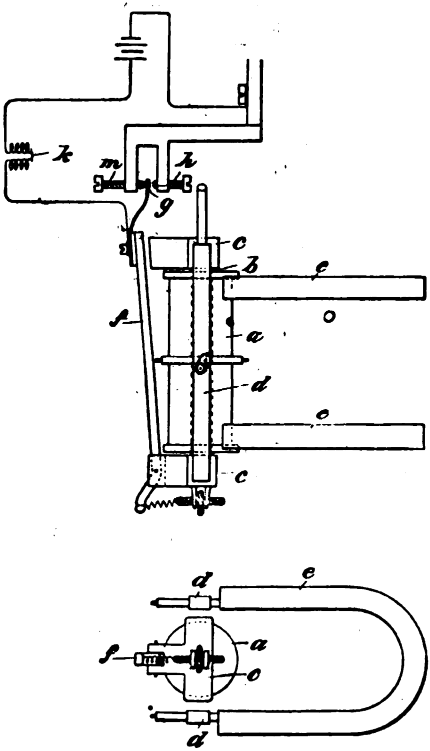

Fig. 256.—Principle of relay.

the inertia to be overcome in starting the typewheel from rest. The feed roller for the paper has an internal spring for feeding the paper up at the end of a line, and this spring is wound up by the electromagnet devices employed in the operation of the instrument.

The typewheel is fixed upon a sleeve which is free to travel longitudinally on its shaft, and the typewheel carriage which slides longitudinally on a stationary shaft has attached to it a cord which passes round a loose pulley at one end of the instrument and then completely round a spring drum situated at the other end of the instrument and back to the typewheel carriage.

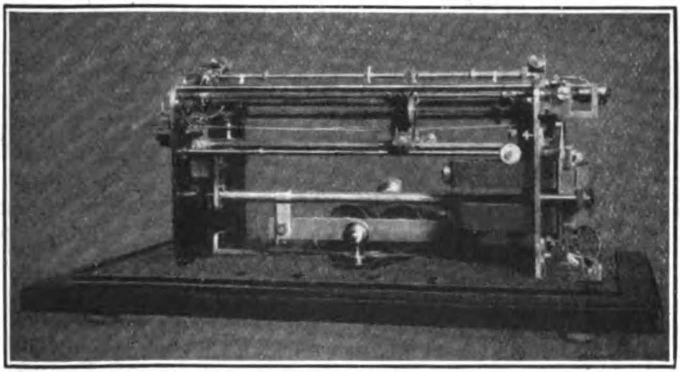

Fig. 257.—Column printer.

The motor for operating the rotating typewheel is similar in principle to the double-tongued polarized relay already described, but the magnets of the tape machine are of special shape, and the two polarized armatures are mechanically coupled together. The details of the working parts will be understood from Figures 258, 259, 260, 261, and 262.

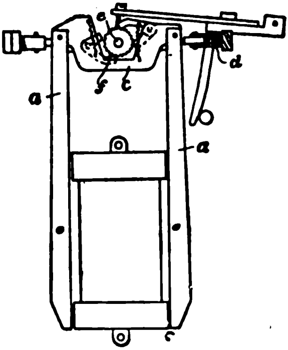

Fig. 258.—Escapement.

The armatures *a*, *a* (Fig. 258) are coupled together by a yoke *c*, and each armature is adapted to compress a small spring *d* at the end of its stroke, so that on the return stroke the recovery of the spring assists the electrical impulses in moving the armature. The typewheel operating shaft *c* (Fig. 259) is divided near the extremity at which the ratchet wheel *f* (which is acted upon by the feed-pawls of the motor) is situated, and the two parts of the shaft, one of which is in the form of a sleeve *g* surrounding a stationary rod, are coupled together by means of a spring connection *h*, thus allowing the motor to start without first having to overcome the inertia of the type-wheel and the portion of the shaft on which it is mounted. In this way the movement of the armatures of the motor can be easily started, so that only small power for operating the motor is necessary. The typewheel *k* (Fig. 260) is fixed upon a sleeve *l*, which is free to traverse longitudinally on the shaft *e*, and the typewheel carriage *m*, which slides on a stationary shaft *n*, has attached to it a cord which passes round a loose pulley at one end of the instrument and then completely round a spring drum *o*, situated at the other end of the instrument and back to the typewheel carriage. This drum is fitted with two ratchet wheels, *p* and *q*, one of which, *p*, is prevented from rotation in one direction by a ratchet-click *r*, and the other ratchet wheel *q* is adapted to be engaged by

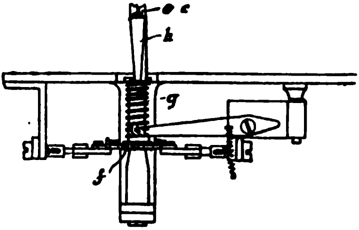

Fig. 259.—Type wheel operating shaft.

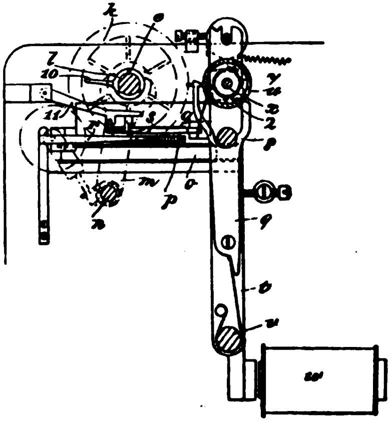

Fig. 260.—Type wheel.

a feed-pawl *s* attached to the printing frame of the instrument. This printing frame consists of a paper-feed roller *u* journalled in side members *t* of the frame, these side members being rigidly fixed to an oscillating shaft *v*, this shaft having attached to it the armature of an electro-magnet *w*, by means of which the printing frame is actuated to bring the paper into contact with the printing wheel. The paper-feed roller comprises a hollow barrel *u* (Fig. 262) mounted so as to be capable of rotation about a concentric shaft *x*, and between the interior of the barrel and the shaft is fitted a spiral spring *2*, one end of which is connected to the shaft and the other end to the barrel. On the shaft is fitted a ratchet wheel *3*, with which a stationary spring-controlled pawl *4* is adapted to engage so as to rotate the shaft and wind up the spring each time that the printing frame is actuated. The spring controlling the feed-click is so adjusted that the click automatically yields to prevent the barrel spring from being over wound, by being restrained by means of an adjustable spring *5*. A second pawl *6* is provided for preventing rotation of the barrel in the opposite direction. At the other end of the barrel and on the axis of the barrel itself is fitted an escapement wheel *7* (Fig. 260) having a number of suitably spaced teeth adapted to engage with pallets on the fork *8* of a spring-biassed reciprocating escapement lever *9*, which is carried by and actuated by the printing frame.

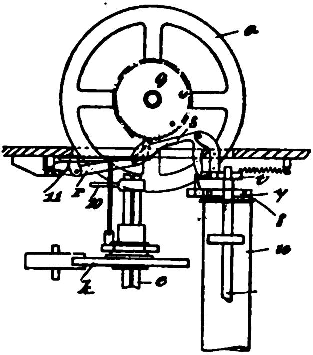

FIG. 261.—Printing frame.

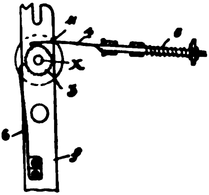

FIG. 262.—Paper feed roller.

As each letter is printed, the printing frame actuates the feed pawl *s* (Fig. 260) of the spring drum *o*, to which the printing wheel carriage is connected, thereby traversing the latter along the paper, and when it is desired to return the carriage at the end of a line, the typewheel shaft is rotated by the motor until a projecting pin *10* provided on the shaft *e* engages the escapement lever *9* of the paper-feed roller. The escapement wheel *7* on the central shaft of the feed barrel is thereby released, allowing its spring to unwind and feed the paper forward through the space of a line. The escapement lever *9* is adapted when moved to release the feed pawl of the spring drum to which the typewheel carriage is connected, and this in turn the stationary click *r* which prevents reverse rotation of the barrel, so that when the feed pawl *s* and click *r* are released a drop-lever *11* operates to maintain both out of engagement with their respective ratchet wheels *q* and *p* until the typewheel carriage returns to its initial position, when the carriage causes disengagement of lever *11* from the feed pawl and click.

The motor for driving the typewheel is connected with the relay already described, so that its movements are synchronous with those of the relay and with the signals transmitted to the latter. The relay controls a contact-making armature in the circuit of the printing magnet *w*, the latter being excited from a local source of supply.

In a tape-printing telegraph the traversing movement of the typewheel is unnecessary, but otherwise the mechanisms for feeding the paper and printing the characters are constructed in a manner similar to those above described.

The line current required for working is 15 to 20 m.a., and the local current for the printing instrument is 30 m.a. for the escapement and 40 m.a. for the printer. The motor for actuating the transmitter is, as a rule, worked by current taken from the electric lighting supply, but as the power required is only about $\frac{1}{80}$ H.P. secondary or primary batteries may be used.

The apparatus is used up to a distance of 300 miles superposed on telephone circuits with bridging coils, but transformers give equally satisfactory results.

CHAPTER XIII

THE HUGHES.

THE Hughes is a directly worked (as opposed to relay worked) synchronous type-printing telegraph, and is very largely mechanical in action. It differs from all other systems in requiring only one current for each character printed and in the fact that the type wheel revolves continuously, no time being lost in the act of printing. The working currents are of equal duration but are separated by unequal intervals of time.

The sending keyboard contains fourteen black and fourteen white keys arranged alternately after the fashion of a piano keyboard. The position of the key depressed determines the instant at which the current impulse is sent out, and the function of this current is merely to release an armature—all the remaining functions, with one exception, are purely mechanical.

The speed of working on cable circuits is greater than the sounder—in fact, it can be worked at its maximum speed on any circuit which will, with shunted condensers, give a Wheatstone speed of forty words per minute (*i. e.* a KR of 450,000). This is accounted for by the fewer currents required and the longer intervals between them. It may also be added that a current of one-half of a milliampere is sufficient to work the instrument, and therefore the voltage applied to submarine cables over which it is worked is not unduly high.

Hughes working is extensively adopted on the Continent, but in this country it is confined to cable circuits working to the Continent and to a few special cases where there are many cable or coded messages.

The type wheel at one end of the circuit is precisely similar to, and revolves in synchronism with, the type

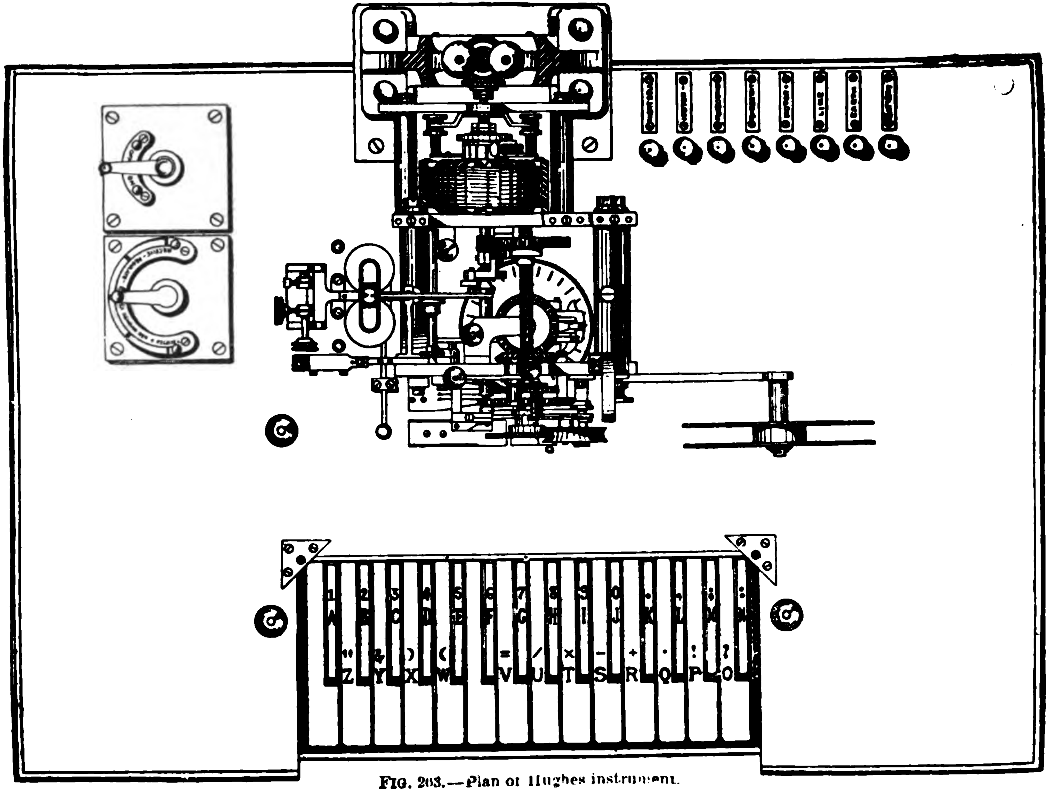

FIG. 203.—Plan of Hughes instrument.

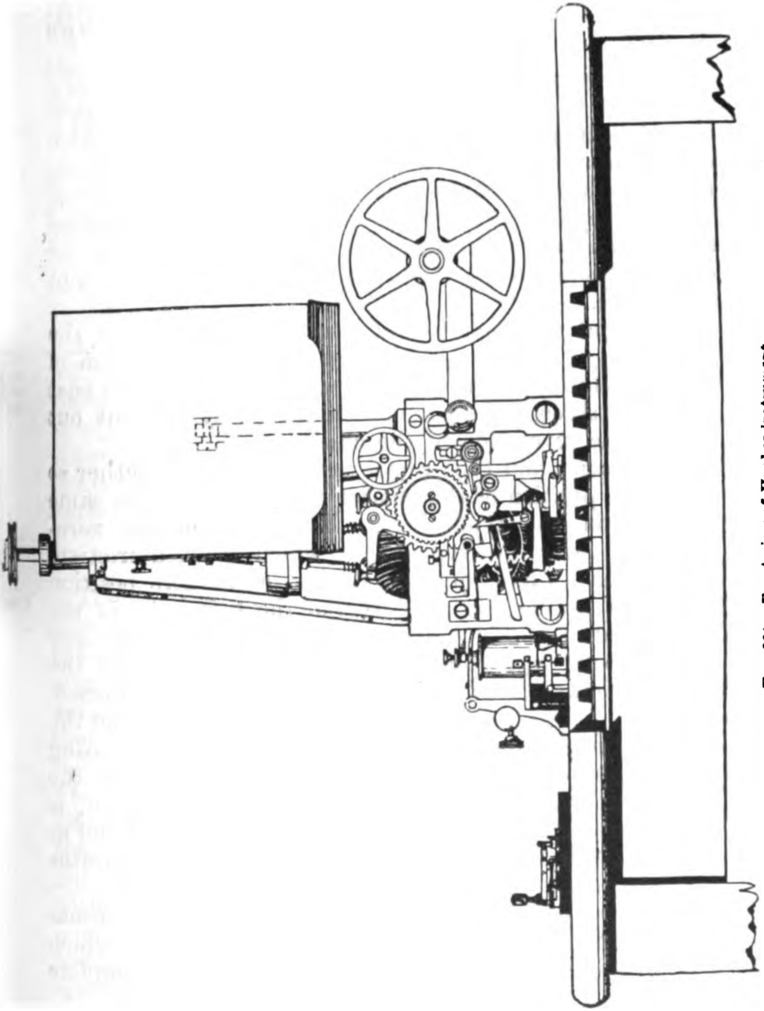

FIG. 284.—Front view of Hughes instrument.

wheel at the other end, *i. e.* not only do the wheels revolve at equal speeds but at any instant the same character upon each wheel occupies a position immediately above the tape.

The twenty-eight transmitting keys are mechanically connected to twenty-eight pins working in radial slots spaced regularly in a horizontal plate. The chariot, which consists of a radial arm carrying a pivoted lever in connection with the stationary contact lever, sweeps over the pins. When a key is depressed the corresponding pin is raised and the end of the pivoted lever moves upwards when the chariot passes over it. This causes a current to be sent out to line.

A current may therefore be sent out at any one of the twenty-eight points in accordance with the position of the key which is depressed. It will, later, be shown that one, two, three, or even four currents may be sent out during one revolution of the chariot.

The chariot and type-wheel normally move together so that each position of the chariot corresponds to the same position on the type-wheel. By means of the zero-adjusting lever, the type-wheel, which is fixed friction-tight upon its axle, may be stopped at its zero position without arresting the revolution of the remainder of the instrument. The depression of the letter blank key releases both type wheels, which start together from the zero position. If, for example, letter "R" key is depressed, the letter "R" upon both type wheels will (neglecting the effect of line retardation, *vide* page 449) be in the printing position at the instant when the chariot passes over the raised pin connected to the "R" key. As the pin is raised the chariot sends a short current out to line and at the same time mechanically operates the home apparatus with the result that "R" is printed at both stations.

The sole function of the current is to release the armature of the electromagnet, the upward movement of which entrains the printing axle, causing it to make one complete revolution.

The revolution of the printing axle, which runs at seven times the speed of the type wheel and chariot, mechanically

(i) corrects the position of the type wheel, thereby securing synchronism, (ii) brings the tape into contact with the inked type wheel, thus printing the character, (iii) moves the tape forward, and (iv) replaces the armature of the electromagnet in readiness for the next signal.

By means of a cam on the printing axle, the position of the type wheel is adjusted so that the particular type is precisely parallel to the face of the paper at the instant of printing. Since at least one, and sometimes three or four, characters are printed during each revolution the frequency of this purely mechanical correction is ample to secure and maintain perfect synchronism between the two instruments.

The instrument is driven by a small electric motor controlled by a rheostat, an adjustable governor serving to maintain uniformity of speed and also to provide a means of adjusting the speed to accord with that of the distant apparatus.

The component parts of the apparatus now call for consideration in detail.

THE HUGHES ELECTROMAGNET.

The two coils, having a resistance of 500^{ω} each, are wound upon soft iron cores polarized by a powerful compound magnet (Fig. 265). The soft iron armature is normally attracted to the cores in opposition to two antagonistic springs. If, for example, the force of attraction is 100 units and the upward pull of the spring is 92, the armature is held down by a force equal to 8 units. The passage of a current through the coils in such a direction as to oppose the magnetism of the cores will cause the armature to be released immediately the attraction is reduced below 92 units. The armature will then fly off with the full force of the spring, *i. e.* with a force of 92 units. In this way the reduction of the attraction by anything over 8 units brings into play the full force of the spring. The upward movement of the armature serves to bring into operation the various mechanical portions of the apparatus which synchronize the two type wheels, print the letter, move the paper forward, and replace the armature.

The value of the attraction between the cores and the armature may be varied by sliding the soft iron bar to right or left as required. The bar (Fig. 266) forms a conducting path for the lines of force, thus reducing the number flowing through the armature, and hence the force of the attraction. When the lever is pushed well over to the right it is evident that the attraction will be least, whilst it will be gradually increased as the volume of that part of the soft iron bar resting upon the right-hand magnet limb is reduced by sliding it to the left.

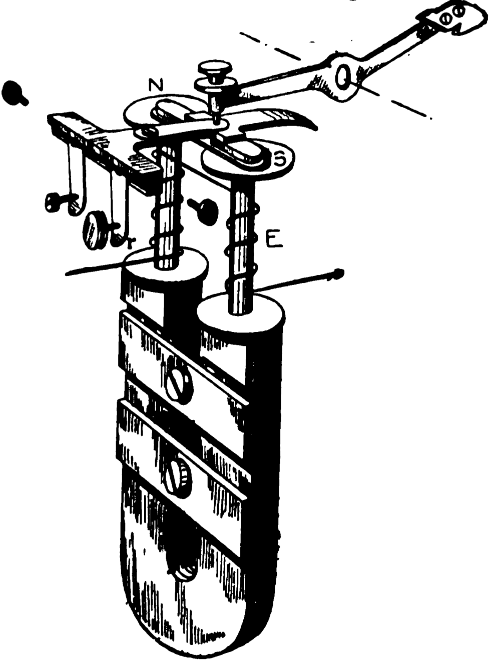

Fig. 265.—Electromagnet.

The upward pull of the armature is produced by two springs acting upon the axle of the armature lever. One spring is of considerable strength, and very rarely requires adjustment. The second spring is of a much lighter description, and is provided with a thumb-screw. This screw is first of all placed in such a position that its thread extends equally upon either side of its support, thus providing an equal range of adjustment in each direction. The permanent magnet armature is next adjusted until the slightest vibration will serve to release the armature. The adjusting screw is then given two turns in such a direction as to reduce the force tending to raise the armature. This provides ample working margin without unduly decreasing the sensitiveness of the instrument.

The position of the electromagnet is adjustable, so as to ensure that the armature shall lie evenly upon the centre of the polar projections. A piece of slip is placed between the armature and the cores, and is secured in position by suitable clips, to prevent "sticking" and to render the action more rapid.

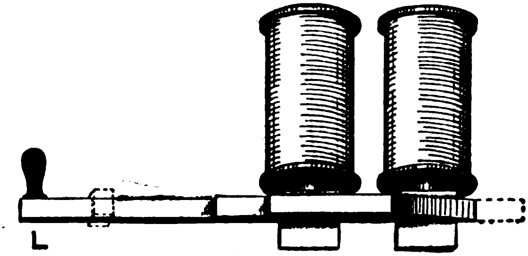

Fig. 266.—Magnetic adjustment.

Motor and Governor.

The motor is driven from the secondary cell installation and its speed is regulated by a 100$^{\omega}$ slide rheostat.

The governor maintains uniformity of speed whether the instrument is printing or running free. The back end of the motor axle carries a bevel wheel which engages with a similar wheel *A* upon the vertical axle *G* of the governor (Figs. 267 and 268). As the axle rotates the two bosses B_1 and B_2 fly outwards in opposition to the force of the springs and the tow brush or brake upon each rod rubs around the inner side of the ring *R*. The tendency to increase speed during periods of inaction is opposed by the increased pressure of the brushes on the ring, and conversely when

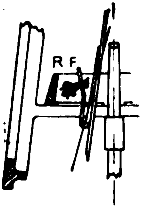

FIG. 267.—Brake on the governor.

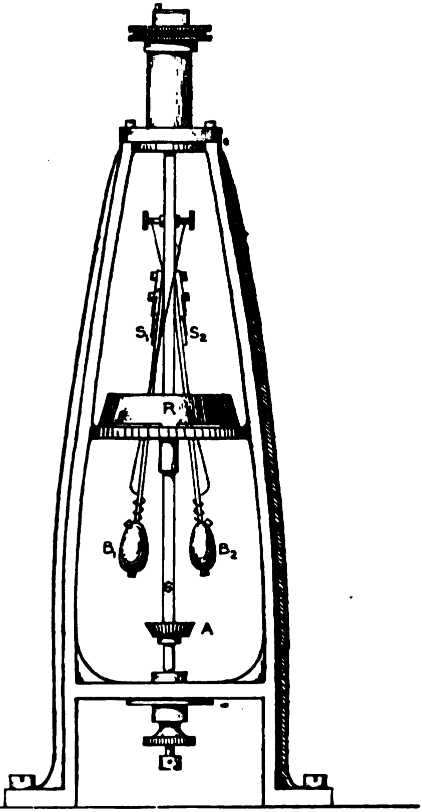

FIG. 268.—View of governor.

the speed tends to drop as the result of the work done in printing, the braking effect is reduced. The extra energy required when the printing axle is entrained is thus obtained and the speed remains remarkably constant. The final adjustment of the speed is made by turning the milled head at the top of the governor.

ELECTRICAL DETAILS.

When the armature rises from the cores of the electro-magnet the number of lines of force is reduced and a magneto-electric current opposing the working current is produced. This is innocuous, save when the circuit is very short. But on replacing the armature the E.M.F. is in the same direction as the working current, and the armature would again be thrown off by its action were not provision made to disconnect the coils whilst the armature is being replaced. A current passing through the coils releases the armature *a* (Fig. 269) which strikes the detent lever sharply and thereby shunts the coils by the 250^{ω} resistance coil. At this moment the resistance of the instrument is 125^{ω}, assuming that the coils are joined in parallel. The printing axle is now entrained, and in revolving the cam *K* disconnects the coils at the contact spring *S*. The connection is not again made until after the armature has been replaced. It will also be observed that during this time the line is

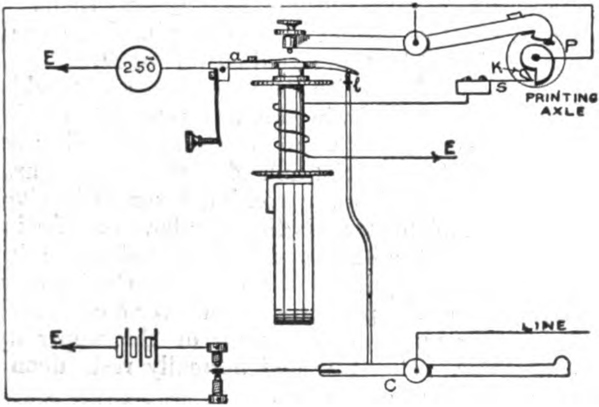

FIG. 269.—Skeleton connections and arrangement of Hughes apparatus.

earthed through the 250^{ω} resistance coil, and this tends rapidly to clear the line of static charge.

It will be observed that the resistance of the instrument varies only from 125^{ω} to 250^{ω}, instead of from 0 to 250^{ω} were the line earthed direct—a definite advantage in duplex working.

THE CHARIOT.

Twenty-eight letter pins, which may be raised by their respective keys, normally rest within the radial slots upon the circular plate shown in plan in Fig. 272. These pins are of the form depicted in Fig. 270, and are normally held in position by the spiral springs attached to them. The depression of a key raises the relative pin above the pin plate, as indicated by the dotted outline at *M*.

The chariot revolves with the type wheel axle to which it is geared by equal bevel wheels and maintained in intimate contact by the upward pressure of the spiral spring *S* (in compression). The chariot axle *A* carries a radial arm *C*, upon the end of which the rocking lever *D* is pivoted. The outer end of this lever is directly above the pins in the key plate, whilst the inner end is connected to the lipped steel collar *E* fixed quite loosely upon the chariot axle *A*. The inner end of the pivoted contact lever *F* carries a projection resting upon the underside of the upper lip of the steel collar. The outer end normally rests upon the contact stud *G*, but clear of *H*.

The chariot sweeps round above the pins, and when it meets a raised pin the inner end of the rocking lever *D* is depressed, so pulling down the collar *E* which raises the end of the contact lever from the stud *G* to *H*. As *H* is in connection with the battery and the contact lever is to line a current is sent out during the time that the chariot is passing over the pin.

THE REJECTOR.

When any particular key is depressed the letter or character it represents is only printed once, no matter how long

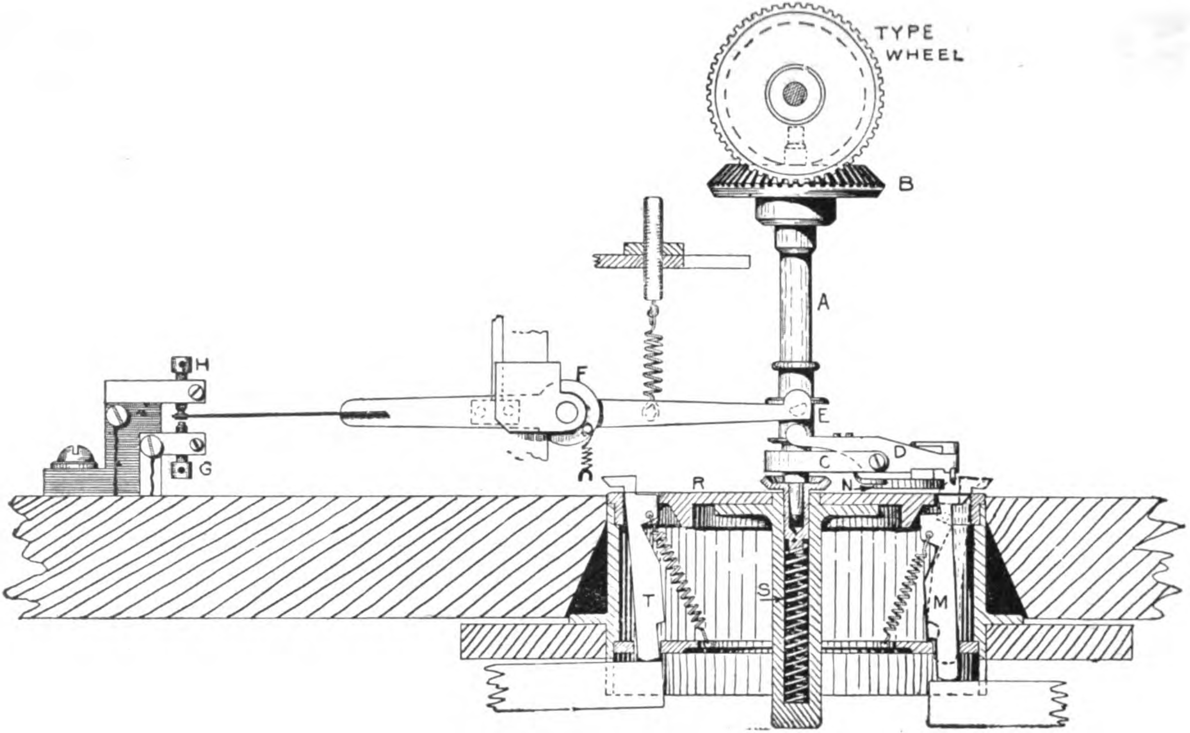

Fig. 270.—Chariot, contact maker and pins

the key is kept down.* Moreover it is impossible to release a pin whilst the chariot is actually passing over it, thus ensuring that every current sent out shall be of precisely equal duration—a matter of very considerable importance These results are obtained by the "rejector," so called on account of its action in rejecting a pin over which it has passed once without the key being released. It is carried upon the arm of the chariot and consists of a steel plate *N* of the shape illustrated in Fig. 271. In order to prevent the breakage of any pin which happens to stick, the

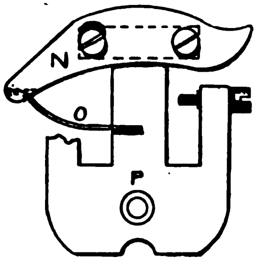

FIG. 271.—Rejector.

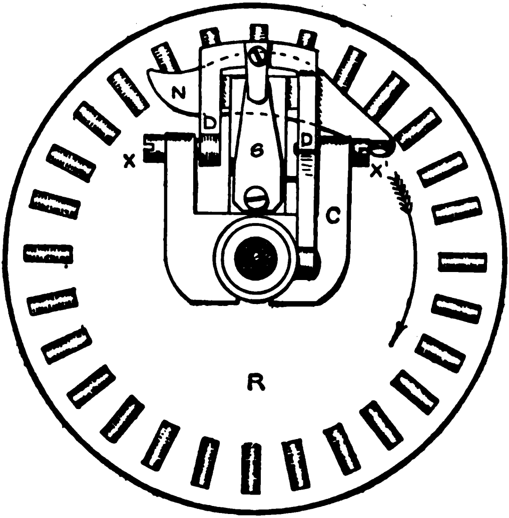

FIG. 272.—Pin plate and rejector.

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* This statement is not strictly true in practice, since a letter may be duplicated by depressing key too lightly. By forcing a piece of cardboard between the letters "G" and "U" a continual call is given to the distant station, currents being transmitted every time the chariot passes the pins.

forward portion of the plate is secured by a screw passing through a slot against the inner end of which it is normally held by the spring *O*. This gives the plate a certain amount of play.

Referring now to Fig. 270, which has been lettered to accord with Figs. 271 and 272, it will be seen that the forked chariot arm *C* carries the contact arm *D*, beneath which is the rejector. Immediately the forward portion of the rejector meets a raised pin, that pin is held until the rejector has passed it, during which time the release of the key in connection with it does not permit the pin to fall back. When the back end of the rejector has passed the pin, it is already pushed back beyond the reach of the contact arm, and therefore when the chariot next passes a second current is not sent out. The letter may, of course, be printed twice if the key is released immediately the chariot has passed and is then depressed again before the rejector reaches the pin.

NUMBER OF CHARACTERS PRINTED PER REVOLUTION.

Mechanical inertia limits the number of characters which can be printed during a single revolution of the type wheel. After the depression of the letter blank key, the next letter which can be printed is "E," followed by "J," "O," and "T," *i. e.* every fifth letter. The chariot, however, covers three pins only in order to provide a working margin.

THE TYPE WHEEL AXLE.

The type wheel axle is driven by the motor and transmits the motion to the chariot by means of bevel wheels. It carries three wheels, (1) the type wheel, (2) the correction wheel, and (3) the ratchet wheel. The ratchet wheel *R* (Figs. 273 and 274) is held in contact with the collet upon which it is mounted by the dished disc *d*. The collet is secured to the axle by the screw b_1, but the ratchet wheel is only friction-tight upon it, and may therefore be held stationary whilst the axle continues to revolve. The ratchet wheel (Fig. 274) is engaged by the pawl *F* fixed to the face of the correcting wheel *C*. By means of the pawl *P* the motion of the correcting wheel is transmitted through the lever *L* to the tube d_1 which is rigidly connected to the type wheel *T* (Fig. 273). This tube passes over the type

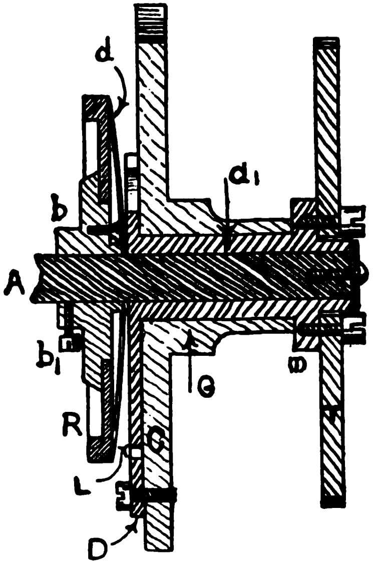

Fig. 273.—Type wheel axle.

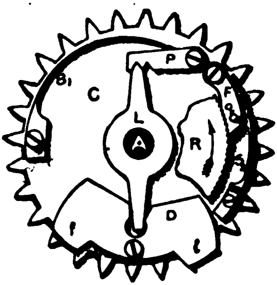

Fig. 274.—Correcting and ratchet wheels; type wheel printing letters.

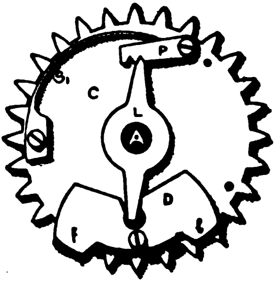

Fig. 275.—Correcting wheel. Change-over from letters to figures.

wheel axle, but is sufficiently loose upon it to prevent the motion of the axle being communicated. Now the correcting wheel is carried upon a second tube which fits loosely over the type wheel axle.

Consideration will show that the type wheel axle (by friction) drives the ratchet wheel, which in turn drives the specially connected correcting and type wheels. The correcting wheel drives the type wheel, but their relative positions are determined by which of the two notches in the pawl is occupied by the type wheel arm. These two positions differ by $\frac{1}{56}$ of a revolution. The relative positions of the ratchet wheel and that of the combined correcting and type wheels may vary to any extent, whilst raising the click *F* permits the ratchet wheel to revolve alone. The provision of this click is merely to avoid damage in the event of the jamming of the type or correcting wheels.

CHANGE-OVER FROM LETTERS TO FIGURES.

The object of the arrangement by which the type and correcting wheels may be relatively displaced by $\frac{1}{56}$ of a revolution is to provide for the printing of figures, signs, and punctuation marks as well as the letters of the alphabet.

Letters and figures alternate upon the type wheel. When it is desired to print figures the type wheel is displaced to the extent of $\frac{1}{56}$ of a revolution by first depressing the "Figure Blank" key. Each unit of time, equal to $\frac{1}{28}$ of a revolution of the chariot, which elapses allows the type wheel to turn through $\frac{1}{28}$ of a revolution, and thus the alternate characters are not printed. For instance, in printing "Jot" the "?" before "o" and the "×" before "t" are passed before the respective currents arrive. With the currents arriving with the same time intervals, but with the type wheel displaced $\frac{1}{56}$ revolution, the characters printed would be "0 (figure, not the letter) ? ×." The fifty-six characters and spaces upon the type wheel are in order as follows:—

Blank Blank 1 *A* 2 *B* 3 *C* 4 *D* 5 *E* 6 *F* 7 *G* 8 *H* 9 *I* 0 *J* . *K* , *L* ; *M* : *N* ? *O* ! *P* ' *Q* + *R* – *S* × *T* / *U* = *V* Blank Blank (*W*) *X* & *Y* " *Z*.

It will be shown later that the position of the type wheel is corrected every time the electromagnet is actuated. This is accomplished by the correcting cam which forces its way between two successive teeth upon the correcting wheel. Now, at two points upon the type wheel blank spaces are left, whilst either of the corresponding positions upon the correcting wheel may be occupied by the projecting portions of the "figure-changing lever." Referring to Fig. 274 it will be seen that the depression of the first or letter blank key will cause the cam to pass between the teeth opposite to *f*. As there is no character upon the type wheel at the point which is directly above the paper, a space is produced. If, however, the correcting wheel had moved so that the right-hand portion of the change-over lever was opposite the correcting cam, then this cam in passing between the teeth would move the figure-changing lever upwards, thus causing the lever to engage the backward notch upon the pawl. This would be the case if the figure blank key was depressed. As already stated, this displaces the type and correcting wheels by $\frac{1}{56}$ of a revolution, so changing over from letters to figures. The change back to letters would of course be made by depressing the letter blank key, when the correcting cam would reverse the position of the cross lever in the notches of the pawl.

PRINTING AXLE ENTRAINED.

The impact of the armature upon the pivoted detent lever Z^1 (Fig. 276), depresses the further end of the lever, thus releasing the click D^1 which descends upon and engages with the continuously revolving ratchet wheel B^1. In this way the printing axle is entrained, but when the click has travelled about $\frac{7}{8}$ of the revolution it reaches the inclined plane E^1. The momentum it has acquired is sufficient to cause it to ride up the inclined plane, so disengaging from the ratchet wheel and finally bringing it back to its normal position of rest against the projecting portion of the detent lever.

Upon the central portion of the click and click-spring arms an eccentric T_1 (Fig. 276) projects sufficiently far to engage the detent lever during revolution. The eccentric, therefore, raises the detent lever, and by means of the

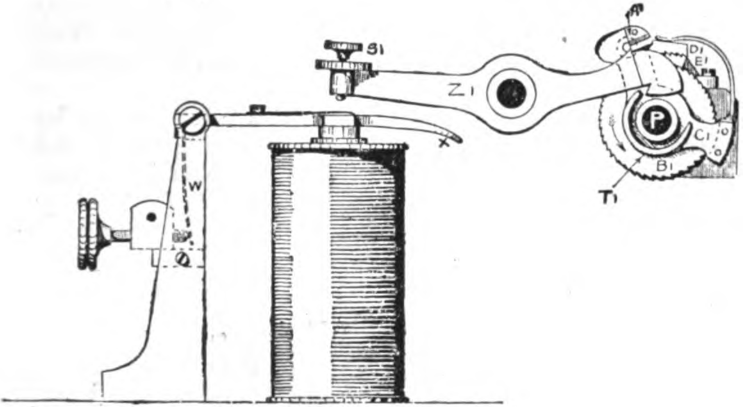

FIG. 276.—Electromagnet and printing axle ratchet.

screw S^1 replaces the armature upon the cores. It will also be observed that the detent lever is in its normal

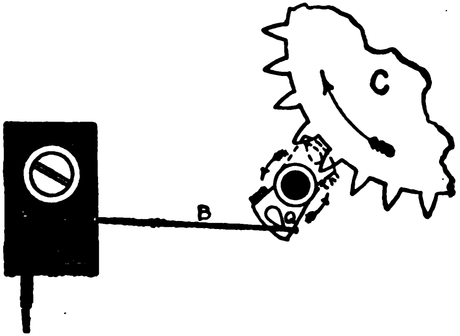

FIG. 277.—Correcting cam and disconnection of the electromagnet.

position before the click disengages, and that it is therefore impossible for the click to overshoot its normal position.

The correcting cam *Q* (Fig. 277) normally rests upon and makes contact upon the spring *B*, but during revolution this contact is broken. This serves to break the circuit of the electromagnet whilst the armature is being replaced.

The other functions performed by the printing axle are effected by three cams attached to the printing axle. They are clearly shown in Fig. 278, and the function of each suitably indicated.

The steel correcting cam Q, which is carried round by the printing axle engages with the correcting wheel, and is so adjusted that when the type wheel is in its correct position, *i.e.* when the letter to be printed is exactly parallel with and wholly in contact with the tape, it lies between the teeth of the correcting wheel as shown by the dotted lines in Fig. 277. If the wheel is slightly behind the position it should occupy, the cam strikes the forward tooth, and so pulls the wheel round to its correct position, always provided that the actual and the correct positions do not differ by more than half a tooth. In a similar way the cam pulls the wheel back to the correct position if the wheel is in advance.

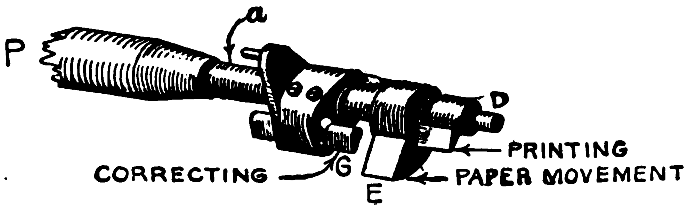

FIG. 278.—Printing axle cams.

The correcting cam is of tempered steel, as also is the correcting wheel. The cam can readily be removed and another substituted whenever signs of wear appear.

PAPER MOVEMENT.

Referring to Fig. 279 it will be seen that the printing lever Q_1, pivoted at m_1, carries a second lever I, known as the paper-moving lever. The slip is carried under m over G, upon which it is pressed by the fork H. In the position shown the paper is in contact with the type wheel due to the cam *D* having completed rather more than half a revolution. This cam, then, working in the forked end of the printing lever raises the paper against the type wheel whenever the printing axle makes a revolution. It should also be noticed that at the moment of printing the correcting cam is exactly midway between two successive teeth upon the correcting wheel. As it is equal in length to the distance between the teeth, the type wheel is steadied, and this no doubt conduces towards the clearness of printing.

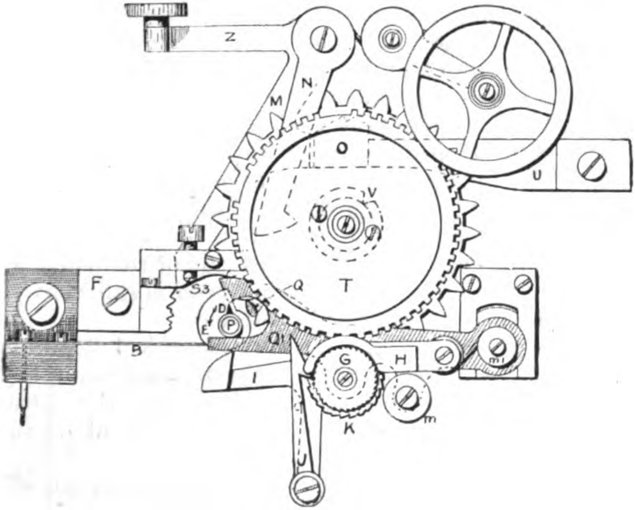

Fig. 279.—General figure of type, correcting, and inking, wheels and printing lever.

A revolution of the cam *E* causes the paper-moving lever *I* to descend to its lowest, and to then resume its normal, position. This downward movement causes the pawl *J* to turn the ratchet wheel to the required extent, and thus to move the paper forward. As the paper roller is carried upon the printing lever the motion of the paper moving lever does not withdraw the paper from the type wheel. The conformation and positions of the two cams are so designed as to reduce the speed of the type wheel as little as possible during printing.

ZERO-ADJUSTING LEVER.

The zero-adjusting lever *Z*, which is to be seen in Fig. 279, provides the means of stopping and starting the instruments at zero. It carries two arms *M* and *N*, the former bearing a wedge-shaped projection.

The click *F* (Fig. 274) which engages with the ratchet wheel *R* carries a pin *q* which normally clears the inclined plane *O* (Fig. 279) carried upon the spring *U*. But when the zero-adjusting lever is depressed the wedge-shaped projection of the arm *M* moves the plane towards the correcting wheel, so that the pin comes into contact with, and rides up, the inclined plane, finally resting in the notch at its apex. This raises the click *F* (Fig. 274) from the ratchet wheel, so disconnecting the correcting and type wheels. The momentum which the combined type and correcting wheels have acquired is sufficient to carry them to such a position that the projection upon the arm *N* (Fig. 279) banks against the forward side of the notch *V*, and the pressure upon the adjusting lever is sufficient to complete the movement already described.

Now the wedge and the inclined plane lock together by means of a suitable catch, and the zero-adjusting key therefore remains depressed. At this point the letter blank portion of the type wheel stands directly above the paper.

If now the letter blank key is depressed a current will be sent out immediately the chariot passes over the letter blank pin. This current causes the printing axle to revolve, thus forcing the correcting cam between the teeth of the correcting wheel, thus moving forward sufficiently far to permit the click *F* to fall upon and engage the ratchet wheel. As the locking between the arm *M* and the inclined plane *O* is of a very slight character the connection is broken, and the pressure of the spring *U* acting upon the wedge restores the zero-adjusting lever to its normal position.

It will be remembered that the printing at the sending station is effected mechanically by an extension of the chariot contact arm, and reflection will show that if both instruments are stopped by means of the zero-adjusting lever both will be started at the zero position when either station depresses the letter blank key.

CONNECTIONS.

The full connections of a Hughes instrument are depicted in Fig. 280, and it will be noticed that two switches, respectively termed the "Hughes" and "motor"

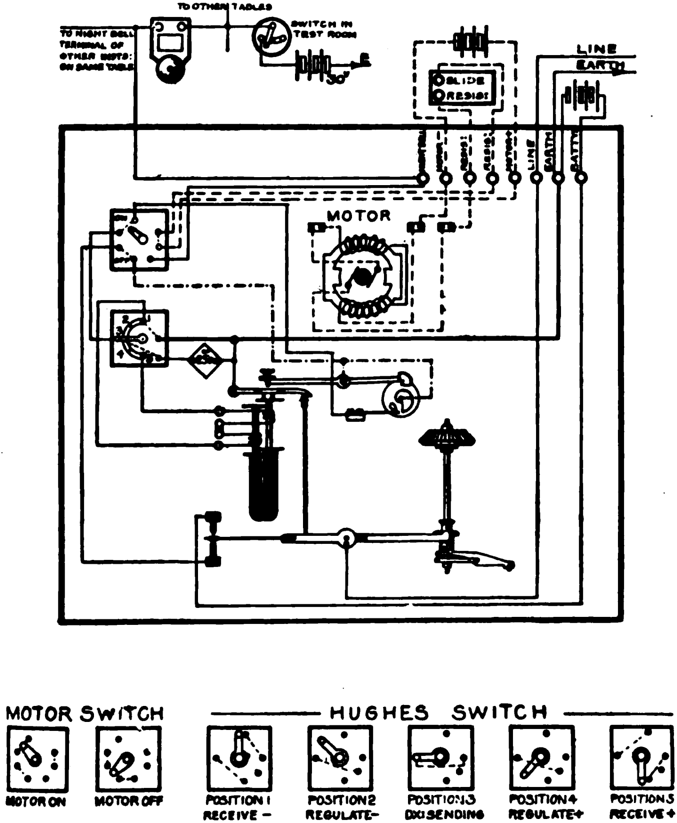

FIG. 280.—Connections of a Hughes set.

switches, are provided. The functions of each of the five positions of the Hughes switch are shown in the following table.

HUGHES SWITCH.

Position of switch.	Functions of Switch in each position.
1. "Receive – " 5. "Receive + "	Determines the direction in which the coils of the electromagnet are connected between line and earth.
2. "Regulate – " 4. "Regulate + "	Disconnects the coils of the electromagnet and earths the line through the 250^{ω} resistance coil.
5. "Duplex sending"	Disconnects the coils of the electromagnet and cuts out the 250^{ω} coil. The line is earthed through the battery coils after each current has been sent out.

When the direction of the current received is such as to increase, instead of to reduce, the magnetism of the electromagnet cores, the Hughes switch at the receiving end is turned from position 1 to position 5 or *vice versa*.

The two positions marked "regulate" produce identical connections. The coils are disconnected and the spring in connection with the correcting cam is connected to the armature. In this way a path to earth through the 250^{ω} coil is provided. If the armature is upon the cores the path is through the correcting cam and spring, but if raised then the path is via the armature.

The "duplex sending" position is dealt with under duplex working.

The motor switch, in the "on" position, joins up the motor. In the second position the connections are changed so that the rising of the armature connects the "night bell" terminal to earth, thus providing a calling signal during slack periods.

PRACTICAL OPERATION.

Considerable skill is necessary to acquire the correct "touch" to operate the instrument. The slight further descent of a depressed key, when the rejector pushes the raised pin outwards, apprizes the sender that the chariot has transmitted the signal, and in this way the sender is enabled correctly to time the depression and release of the keys. The usual speed of the chariot is 120 revolutions per minute, which at three letters per revolution gives a working speed of 60 words per minute, but in practice the speed may be taken as 44 words per minute. It should be added that letters should be printed, and synchronizing corrections thereby obtained, as frequently as possible.

A series of conventional signals is arranged to provide calling ("Blank *N*" repeatedly), answering ("Blank, Blank"), operating and adjusting signals, many of which are read by sound, and are thus independent of the printing arrangements.*

Before connecting the instrument to line, the electromagnet is adjusted as described on page 432, and it is ascertained that the speed does not drop when printing five characters ("Blank *E J O T*") during several successive revolutions of the chariot.

The instrument is then connected to line and the distant station sends a succession of "blanks" which if received as "*A B C D E*" indicates that the home instrument is fast, whilst "*Z Y X W*" denotes that it is slow. The governor is adjusted until the blanks are received correctly. The line is then disconnected for ten revolutions and if on switching in blanks continue to be received correctly, the speed adjustment is between the station sufficiently accurate.

The final adjustment of the electromagnet is then made by the passage of working currents ("Blank *I N S*" is employed).

EFFECTS OF RETARDATION.

Upon a long circuit there is, of course, a considerable amount of retardation. If the two type wheels both have their blank positions above the paper at the instant when a signal is sent out from the first station a letter will probably be printed at the distant station. This will be due to the fact that during the time taken by the current to appear at the distant end the type wheel is moving forward. The actual time may readily be measured by observing the letters printed when each station alternately depresses the "letter blank key."

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* Technical Instructions VI, The Hughes Type-Printing Telegraph System (Wyman & Sons) details the Conventional signals and gives practical directions for the examination and adjustment of the apparatus.

In practice the sole qualification for satisfactory working is that the currents transmitted shall not merge into one another—the actual time occupied by the current in rising to the value necessary to work the instrument being immaterial. Supposing that the retardation amounted to a quarter of a revolution of the type wheel it will be obvious that the distant type wheel would not be released until a quarter of a revolution later than the sending station's, hence the characters would be received correctly. Upon the other hand both instruments must be stopped at zero before the direction of sending is changed.

The speed of working, which is directly proportional to the speed at which the chariot revolves, varies with different circuits. Upon a long circuit the speed has to be reduced in order (1) to prevent isolated currents being lost, and (2) to avoid the prolongation of a series of closely spaced currents (*e.g.* as sent when signalling "*I N T*"). In the second case the successive currents would merge into one another owing to the capacity of the circuit being so large that the earthing of the line is insufficient to clear it of charge. Hence the charge increases in value with each closely spaced current, the final result being that an extra letter or two is printed due to prolongation.*

HUGHES DUPLEX.

The Hughes may be duplexed by either the differential or bridge methods, but in the former case a relay must be employed since the Hughes electromagnet, although possessing two coils, is not differentially wound. With regard to differential working it need only be said that the sending Hughes is connected to the split of a standard relay and the receiving Hughes with a local battery and a 1000^{ω} resistance coil to *T* and *M*. The duplex balance requires to be extremely accurate and it is necessary also to reduce the interval of break between the contacts of the sending Hughes to the smallest possible limits. Definite advantage is gained by the use of the 250^{ω} coil which reduces the resistance variation of the receiving instruments in bridge duplex working from 250^{ω} to 125^{ω} (page 392).

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* If the reader does not follow this statement it is advisable that p. 354 should be referred to, since the present case is but an obvious extension of that which has been said in regard to the speed of working upon Wheatstone circuits.

In both differential and bridge duplex methods a single current sounder is added for balancing and for communicating with the repeater stations. Likewise, a battery resistance coil in which is inserted resistance equal to that of the sending battery is interposed between the lower contact of the sending Hughes and earth (page 255 and Fig. 133).

Signalling condensers cannot be employed owing to their effect in clipping the first portion of the received signal; further, their effect in charging the line to a greater extent before the instrument is actuated reduces the frequency with which successive signals may follow each other without running together.

In the case of inland circuits the speed of working is about 220 letters (120 revolutions of the chariot) per minute. Upon the London-Rome circuit the speed is about 160 letters, but in this case there are four repeaters in circuit (Paris, Lyons, Turin, and Florence).

Duplex Resistance Coils.

The duplex resistance coils are of similar design to those used in connection with Wheatstone circuits, but are wound to a resistance of 1000^{ω} (instead of 3000^{ω}) per coil.

Inductive resistance has been employed in place of the non-inductive duplex resistance coils with the object of reducing the shunting effect on received signals but without any measure of success. The coils are

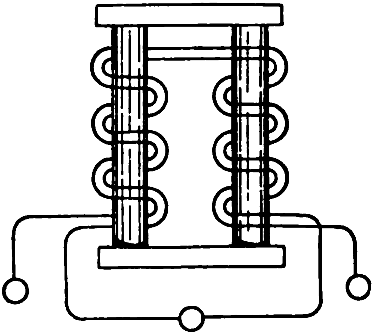

Fig. 281.—Electromagnetic duple resistance coils.

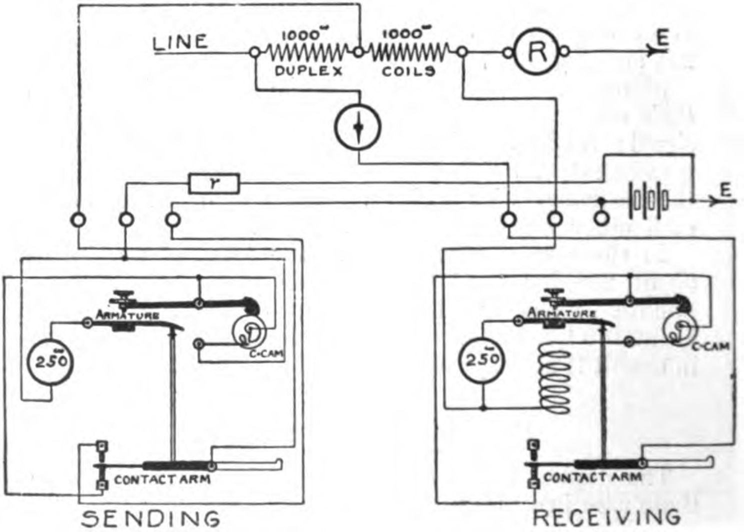

Fig. 282.—Principle of duplex working and skeleton connections.

differentially wound and have a closed magnetic circuit, and are therefore non-inductive from the centre out-

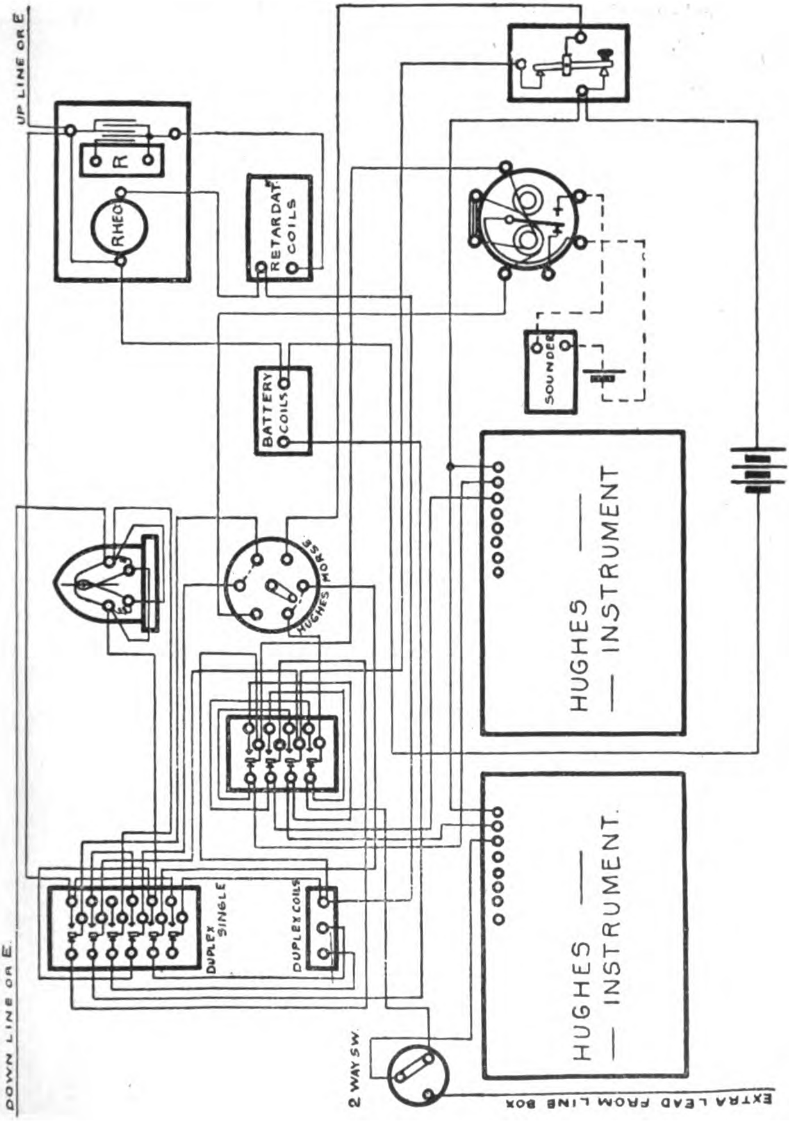

FIG. 283.—Full connections of duplex set. (An extra differential galvanometer is usually placed in circuit on the extra lead to the line box.

wards to line and compensation circuit but inductive in series.

A device which has been employed to substitute signalling condensers is termed an electromagnetic leak. Upon either side of the duplex resistance coils an earthed electromagnet is connected. The self-induction produces an effect similar to that of a signalling condenser by offering a very high resistance to the first portion of the sent current, whilst its ohmic resistance only is active when the current has attained a steady state.

The device is in use upon a few Wheatstone worked cable circuits at the repeater stations, but with a somewhat different object. It has never been used to any considerable extent by the Post Office.

The duplex connections are shown in skeleton in Fig. 282 and in full in Fig. 283. The single current sounder apparatus is brought into circuit by turning the 6-terminal 2-position switch to the right. The change from single to duplex is controlled by the 6-bar switch whilst the 4-bar switch crosses over the sending and receiving apparatus.

CHAPTER XIV

THE BAUDOT.*

INTRODUCTORY.

MULTIPLEX telegraphy † consists in giving, successively, the exclusive use of the line for equal periods to two or more operators.

In the Baudot system each operator has a keyboard furnished with five keys, and in order to signal any particular letter the keys are depressed in the appropriate combination. The depressed keys determine the direction of the five successive currents sent over the line. These five currents energize five receiving electromagnets which are connected to line in turn, and in this way the position of the sending keys is reproduced by the armatures of the receiving electromagnets. The position of these armatures, then, by purely mechanical means selects, prints the character on the tape, feeds the tape forward, and returns the armatures to their normal positions. The time in which the five current impulses can be signalled even over lines of considerable length is far less than that required by an operator to form the combination corresponding to the letter to be sent. These permutations of five currents are therefore transmitted rapidly, and the idle line time, during which the operator is forming or setting up the next letter combination, is used to transmit other sequences of five currents set up by other operators.

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* Abstracted from A. C. Booth's paper "The Baudot Printing Telegraph System," read before the Institution of Post Office Electrical Engineers, March 11, 1907. This chapter has been revised by W. A. Hatfield. Poulaine and Faivre's *Cours d'Appareils Baudot* gives a full and detailed account of the system.

In English there are Crotch's "Hughes & Baudot," and Pendry's "Baudot System."

† The first practicable system, the Meyer, invented in 1872, is described in *Electricity in the Service of Man*, revised by R. M. Walmsley (1890 edition). The Delaney system, formerly used by the Post Office, is described in Chapter X of the 1905 edition of Preece and Sivewright's *Telegraphy*.

The Baudot system enables from two to six operators to work over a single line connecting two stations, the arrangements being respectively termed Baudot double, quadruple and sextuple. Each channel may quite independently be worked in either direction at will, and this constitutes a distinct advantage at times when sudden pressure arises in one direction. The system can also be applied to extended circuits; for example, a single wire connecting *A*, *B* and *C* can be used to give the following channels: *A* to *B*, *B* to *A*, *A* to *C* and *C* to *A*—in fact, the facilities which can be secured are quite equal to those afforded by the quadruplex sounder. Repeaters and retransmitters can be interpolated in a Baudot circuit with great advantage on very long circuits.

The Baudot may be duplexed, giving double duplex, triple duplex, quadruple duplex, quintuple duplex, and sextuple duplex.* With the sextuple duplex there are therefore six channels in each direction, and twelve messages are sent simultaneously over a single wire.

PRINCIPLE.

The Baudot system is based on the use of a five-unit code. Each letter is of precisely the same length, and is transmitted by permutations of five positive and negative currents. There is no space between the various letters composing a word. The manipulation table is shown in Fig. 284, the change over from letters to figures and *vice versa* is arranged as in the Hughes, keys 4 and 5, depressed singly, respectively being employed.

A rotating arm, which successively passes over five segments connected to the five keys, moving in synchronism † with a similar arm passing over the five segments connected to receiving electromagnets, is employed to send the five currents forming each letter (Fig. 285). In quadruple or four-channel working, which is the arrangement usually adopted, the rotating arm (Fig. 286) carries two brushes connected together but insulated from the arm.

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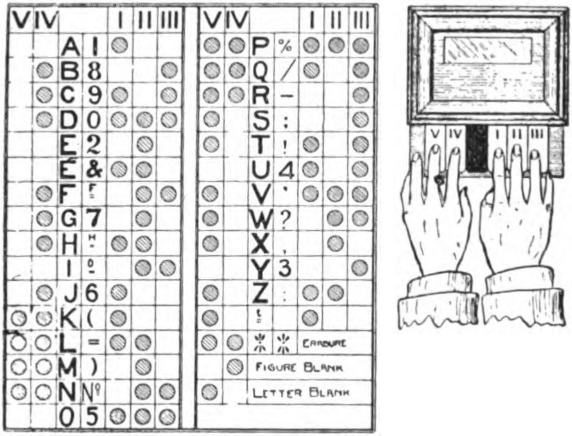
* The details of this arrangement are given by A. C. Booth in the *Post Office Electrical Engineers' Journal*, Vol. III. p. 336 and Vol. VI. p. 324.

† Defined on page 480.



V	IV			I	II	III	V	IV			I	II	III
		A	1	●			●	●	P	%	●	●	●
	●	B	8			●	●	●	Q	/	●		●
	●	C	9	●		●	●	●	R	–			●
	●	D	0	●	●	●	●		S	:			●
		E	2		●		●		T	!	●		●
		É	&	●	●				U	4	●		●
	●	F	F		●	●	●		V	'	●	●	●
	●	G	7		●		●		W	?		●	●
	●	H	H	●	●		●		X	,		●	
		I	o		●	●			Y	3			●
	●	J	6	●			●		Z	:	●	●	
○	●	K	(	●			●		t		●		
○	○	L	=	●	●		●	●	*	*	ERASURE		
○	○	M	)		●			●	FIGURE BLANK				
○	○	N	N°		●	●	●		LETTER BLANK				
		O	5	●	●	●							

Fig. 284.—Manipulation table.

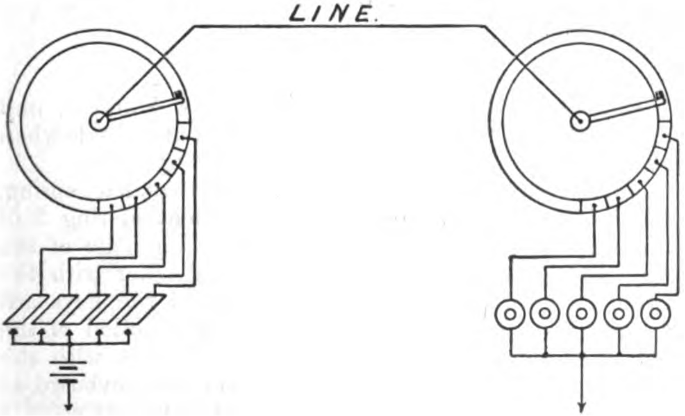


Fig. 285.—Principle of Baudot.

The inner brush is in continuous contact with an unbroken ring to which the line is joined, and the outer brush makes connection with the four sets of five segments. In this way signals are transmitted in either direction by each operator. It will be seen later that additional signals are interpolated to secure synchronism and also to allow for the delay in the arrival of the received current at the distant end.

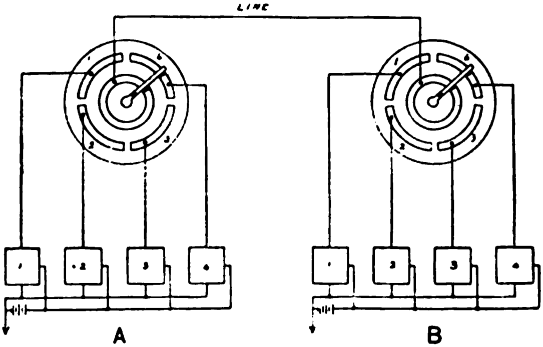


FIG. 286.—Principle of Baudot quadruple.

KEYBOARD.

Keys 1, 2, 3 are separated from keys 4 and 5, and a "send" and "receive" switch is placed at the side when the set is required for simplex working (Fig. 285).

Each key has at its inner end a vertical flat spring, which is connected to its particular segment of ring 2 of the sending plate on the distributor, the segments of the ring being thus connected in numerical order with the twenty keys of the four keyboards. When the keys are at rest in the raised position due to the action of the helical springs, all the flat springs make contact with the brass plate extending the full width of the keyboard at the rear; and when a key is depressed it makes contact with a similar brass plate in the front of the keyboard.

The marking battery, which usually sends out positive currents, is joined to the front plate, whilst the spacing battery (negative currents) is joined via the keyboard switch to the rear plate.

It is essential that the operator should know the correct moment when to depress the keys, viz., just before the distributor brush reaches his No. 1 segment or key, and the "time-tapper" or "cadence" is therefore provided in the shape of a single-stroke hammer on the keyboard, actuated electrically by the distributor.

It is also necessary to guard against the operator allowing the keys to rise too early, viz., before the distributor brush has passed off the last of the five segments.

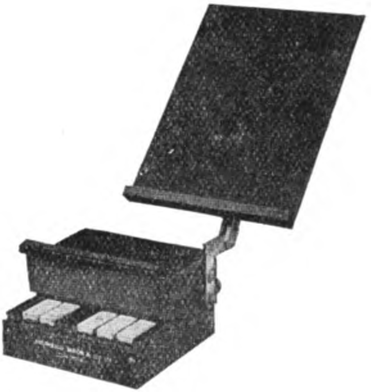


FIG. 287.—Keyboard.

In the latest keyboard all five keys, when once they have been depressed, are held down mechanically by five

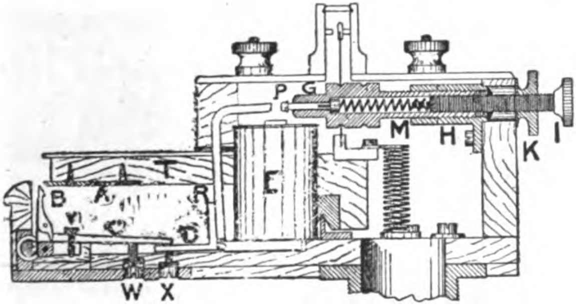


FIG. 288.—Keyboard with mechanical locking.

separate hooks *B* (Fig. 288), until they are released by the passage of the cadence current through the electromagnet *E* which attracts the armature *R*. The latter strikes the stop *P*, giving the warning signal to the operator, and at the same time tilts the lever *C* by means of the extension *D*, thus throwing back the hooks *B* and allowing the keys to rise.

THE RECEIVER.

The receiver (Fig. 289) is driven by a small electric motor, and is provided with a governor and an electric brake, the latter comprising an electromagnet which, when energized, presses a cork pad on to the rim of the fly-wheel, normally running at from 1600 to 1800 revolutions per minute. The governor in conjunction with this brake maintains uniformity of speed, in spite of the fact that more work is performed when printing than when running free. The receiver top, which is

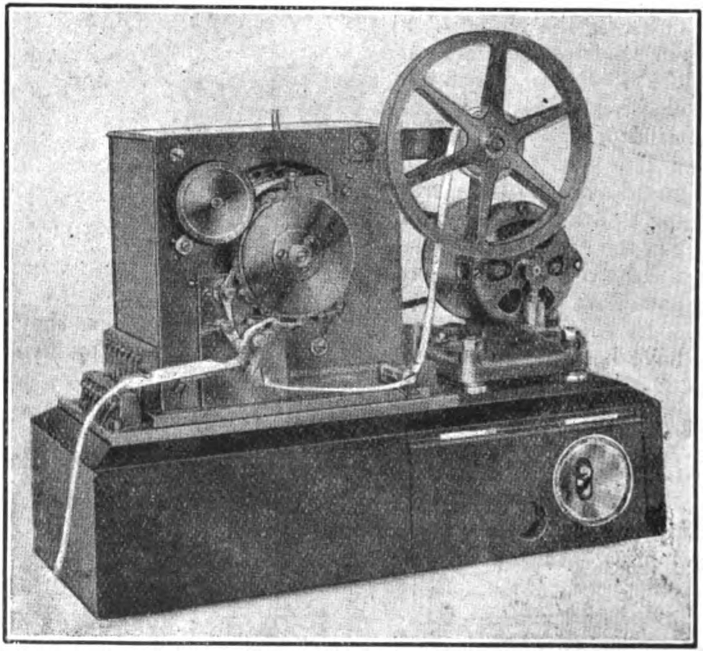


FIG. 289.—Baudot receiver.

readily removable from the lower part, contains five electromagnets connected to the distributor so as to receive the marking currents sent out by the five keys of the sending keyboard. One of these electromagnets is shown in Fig. 290. Its armature *aa* when attracted moves the vertical portion of l_1 on to the rim of gear-wheel *R*. On one side *R* carries the marking and spacing discs D_1 and D_2, which are separated by a ridge with two small gaps. On the other side of *R* is the rim *b*, in which there is also a gap and a double cam *K*. As the wheel *R* rotates, the point of the cam *K* passes to the front or rear of the tails of the "pointsman" levers *l*,

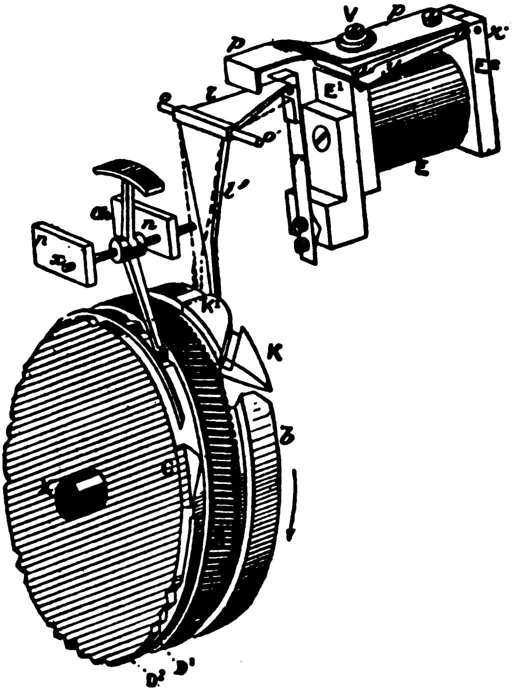


FIG. 290.—Electromagnet, selector, and combiner wheel.

according to whether they are in their normal positions or whether they have been moved by the electromagnets. The tail of any depressed lever is forced by the cam *K* along the groove towards *R*, and immediately afterwards is restored to its original position clear of the disc *b*.

The tails of the levers *l* when passing through the groove of the cam *K* press against the ends of five spindles *x* and drive them forward in their bearings *nn*. These spindles have a double motion: they can slide to and fro in their bearings, and can also rotate to a limited extent. Each spindle carries a curiously shaped lever *ch* termed a "selector," whose upper portion is wide and curved, whilst its lower or tail portion is oblique and narrow so as to travel in either of the grooves of the discs D^1 D^2. When the tails of the pointsman levers are acted upon by cam *K* so as to drive forward the spindles *x* and consequently the selecting levers, it is arranged that the tails of the latter are just opposite the opening above the cam *C*, and are therefore able to pass through from the disc D^1 to the disc D^2, where they remain for almost a complete revolution, being returned to disc D^1 by the cam *C*.

The heads of the selecting levers $ch^{1, 2, 3, 4, 5}$ (Fig. 292) form an arc, each one touching its neighbour. The sixth head L^1 has a spring and an arm L^2 clamped to its spindle, the spring being pressed downwards by an adjustable screw, tending to push the head of the lever towards the right. In this way all the heads of the selecting levers are held in contact with each other and are pressed over to the right, in which direction their movement is limited by the tails of one or more of them pressing on one or other of the discs.

The heads are made sufficiently deep to support the heads of adjacent levers even though their tails may be on different discs.

The discs are provided with shallow grooves or hollows corresponding to the combinations of the Baudot code, and where there is a hollow on one disc there is no hollow on the other and *vice versa*. In the rear disc, which might be termed the spacing disc—that is to say, the disc where the selecting levers remain so long as only spacing currents are being received—there is no position where five hollows occur consecutively, hence there is no movement of the head L^1 during a complete rotation of the discs; but in the front disc hollows occur opposite no hollows on the back disc; therefore if any one or more selecting levers be made to pass through the gap to the front disc there will be one position per revolution where all five tails will be above hollows into which they will drop due to the pressure of the head of L^1. They are then almost immediately jerked out again owing to one or more ungrooved portions coming beneath one or more of the tails. This jerk is of sufficient strength not only to restore the heads to the normal position, but even to make them overshoot that position, and in that movement the horizontal arm L^2 acts on the lever B^1 which releases the printing gear.

The rims of the discs and type wheel are represented in Fig. 291 as rolled out flat. The five pointsman levers are indicated by l^1 to l^5, three being in their normal position, while two have been acted on and are ready to be collected by the cam *K* on its passage upward. The selecting levers are indicated by ch^1 to ch^5, and it will be observed that although

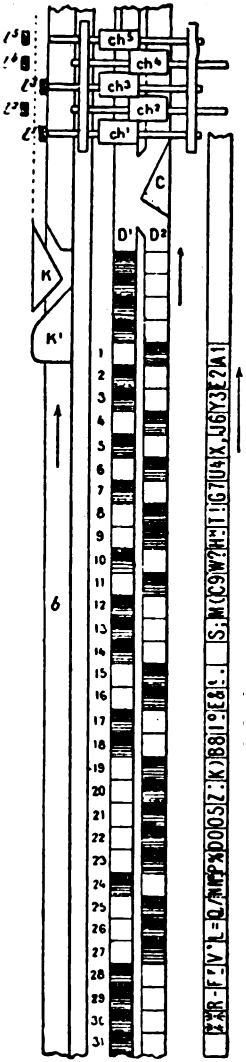


Fig. 291.—Plan of combiner and type wheels.

the tails are in different grooves, each head supports the one next above it. In the previous revolution ch^2 and

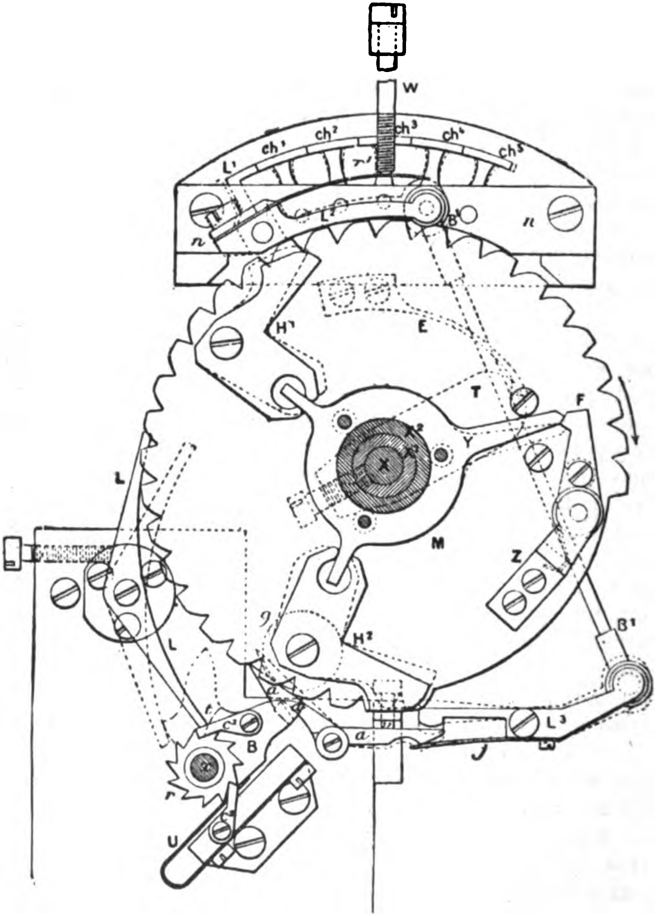


FIG. 292.—Retention wheel and figure change mechanism.

ch^4 were acted on, and having done their work they are about to be restored by cam C to their normal position: if, however, l^2 and l^4 had again been depressed, ch^2 and

ch^4 would pass immediately behind cam *C* to disc D^2 through the groove shown. In the case indicated, *ch^1* and *ch^3* will pass to D^2, as l^1 and l^3 will pass through the groove of cam *K*.

The shaded portions of D^1 and D^2 represent the hollows, while the unshaded portions represent no hollows. In looking down the two discs to find a combination of hollows to suit the position of the five selecting levers, it will be observed that there is only one position that fulfils this requirement, viz., position 76543, and opposite 7 will be found the letter *G*, which corresponds with the code already given. Taking the case for the next revolution the only position is that of 65432, which gives the letter U.

The type wheel and printing gear are represented in Fig. 292. Here again are the selecting levers *ch* and the head L^1 with its spring and adjustable screw *W*, also the arm L^2. The rod B^1 communicates the motion of L^2 (shown by the dotted lines) to L^3 pivoted at its centre. The unattached end of L^3 has therefore a reverse motion to L^2, that is to say, when the selecting levers drop into hollows, L^2 falls and the unattached end of L^3 rises; then as the selecting levers are jerked out of the hollows L^2 rises to the upper dotted position, while L^3 falls into the lower dotted position, striking in its passage the lever *a*, whose left-hand end in the form of a hook normally engages a pin on the spear-shaped piece *B*, pivoted at *x*. Owing, to the action of L^3 the hook of *a* rises and releases *B*, which is forced upwards by the spring *U*, and reaches the rim of the large toothed wheel *M* when its point enters the first gap that follows. *B* is carried forward by the wheel *M* till it reaches the dotted position shown, and remains there until a roller *g* on the wheel *M* engages the upper end of the lever *L*, forcing its lower extremity to the right, *L* thus restoring *B* to its original position beneath the hooked lever *a*. The passage of *B* past the toothed wheel always occurs at the gap in the wheel *M*, where it can meet no obstruction, as it could not of course be replaced at any other portion of the wheel.

The type wheel *N* is situated in front of, and is attached to, the toothed wheel *M* in a manner somewhat similar to the Hughes, by being rigidly connected with the lever *Y*.

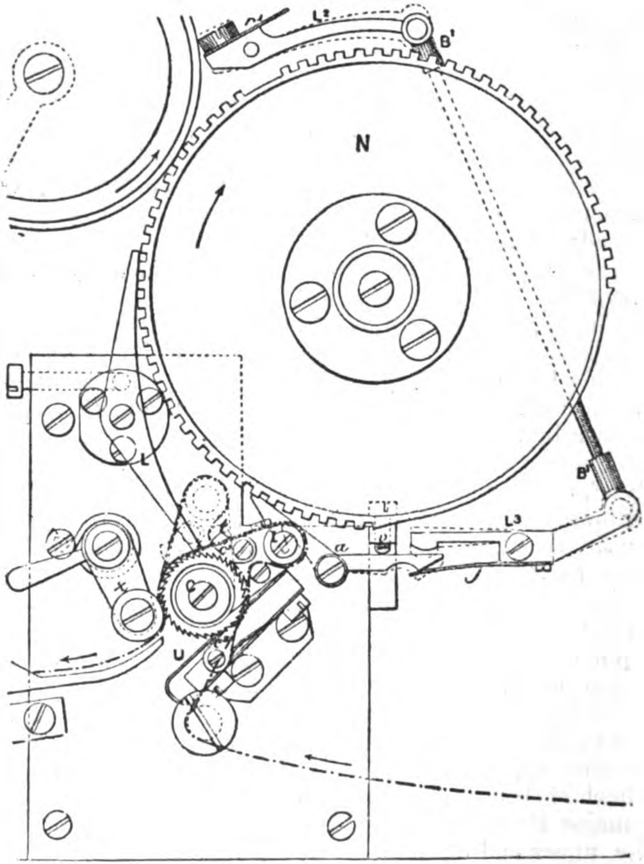


Fig. 293.—Type wheel and paper movement mechanism.

The latter is capable of taking up either of two positions according to its controlling levers H^1 and H^2, which are themselves acted upon by the point of the lever *B* when it passes into their respective gaps. In one of these positions the type-wheel prints letters, in the other, figures. The change is made by the signals already given in the code (Fig. 284). To prevent any damage in case of accidental fouling of the printing gear, the toothed wheel *M* is not rigidly attached to the main axle *X*, but is connected by a friction clutch arranged by the spring *E* on the wheel engaging with the grooved end of the piece *T* clamped to the axle. The wheel disengages itself by allowing the piece *T* to force itself clear of the spring *E*. The angular piece *F* serves to hold the lever *Y* rigidly in one position or the other; the screw *v* limits the engagement of the hook of *a* with the pin of *B*; the spring *j* ensures certainty of engagement; and the pawls c^1 and c^2 serve to drive forward the toothed wheel *r* as *B* moves to and fro.

The paper slip is shown by the dotted line (Fig. 293) passing around the small roller *I* pivoted at the pointed end of the lever *B*, while the toothed roller *C* is rigidly connected to the ratchet *r*. Hence as *B* moves upwards it presses the roller *I*, carrying the paper, against the type wheel, thus printing the required letter. The roller *I* does not rotate in the forward movement, because the pawl c^1 drives forwards the ratchet *r* and with it the wheel *C*. On the return movement of *B* the pawl c^2 prevents the backward movement of the wheel *r*, hence the paper is fed forward on the roller *I* ready for the printing on the next signal. The jockey roller *Z* ensures the engagement of the slip with the fine teeth of the roller *C*. Above the lever *L* is situated the inking wheel which supplies the ink to the rim of the type-wheel.

THE DISTRIBUTOR.

Like the Receiver, the distributor (Fig. 294) is in two parts, a base and a top. The base is similar to that of the receiver except that it carries the regulator and has neither electrical connections nor electric brake. The driving mechanism is by a falling weight and gearing.

The Distributor top supports two ebonite discs (Figs. 295 and 296) or plates, one in front known as the movable or receiving disc, and the other at the rear known as the fixed or sending disc. Both are of the same size, and each carries six contact rings, some complete, others divided into segments of various sizes. The electrical connections are made at the back of the discs, three small cables being taken to a connection box conveniently situated.

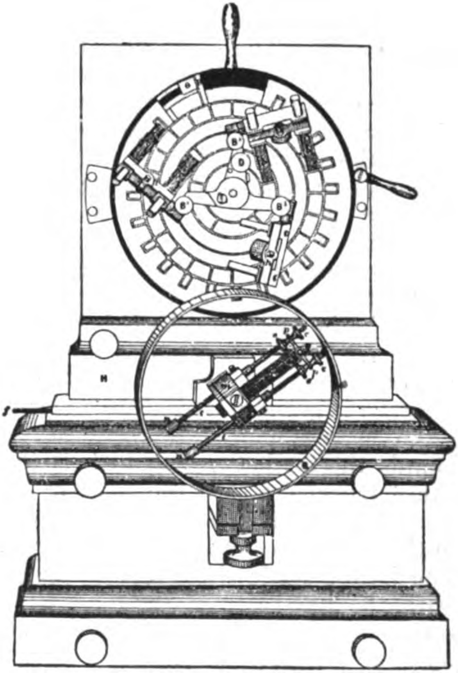


Fig. 294.—Quadruple distributor, front view. Rings VII–XII.

The front plate is traversed by four brushes attached to a three-armed support which is rotated by a spindle passing through the centres of both discs. Each pair of brushes is connected electrically but is insulated from the portion of the support. The right-hand pair of brushes therefore form a connection between rings 2 and 5; whilst the left-hand pair connect 1 and 4. The lower support is not provided with brushes, as rings 3 and 6 of

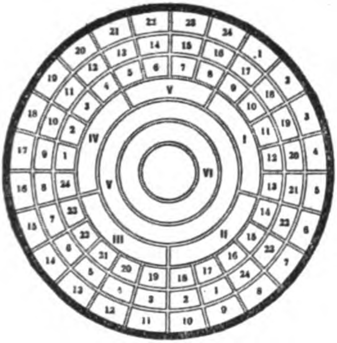


FIG. 295.—Quadruple distributor. Back plate.

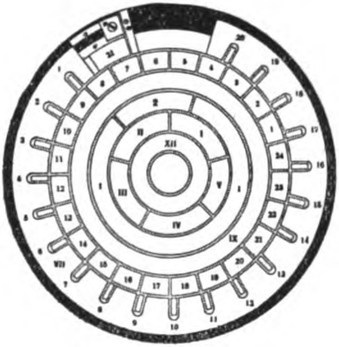


FIG. 296.—Quadruple distributor. Front plate.

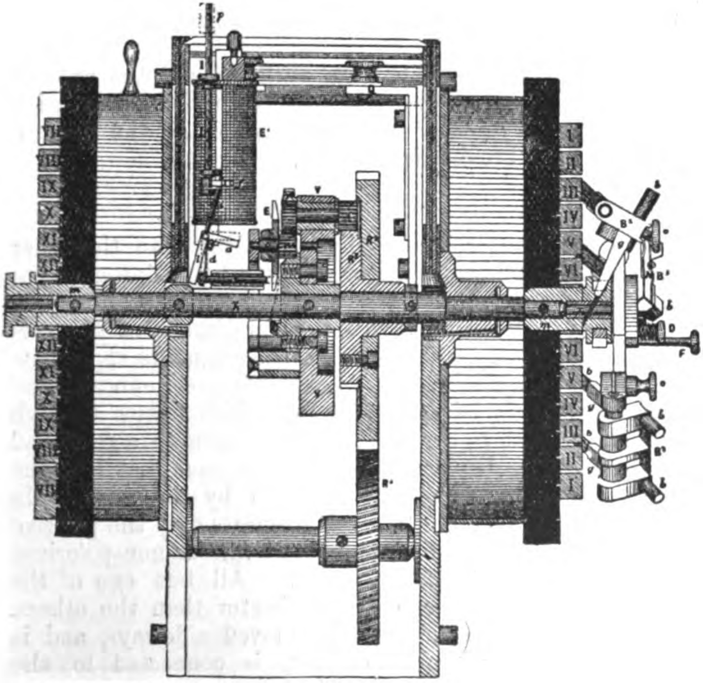


FIG. 297.—Distributor. Sectional drawing.

the front disc are not required. The third support is provided so as to balance the revolving mass of the brushes. On the rear disc all six brushes are used. The handle at the top is for moving the whole disc to the right or left as required, and the handle at the side for clamping it in any desired position. The regulator, shown beneath the disc, travels at ten times the speed of the brushes, and is surrounded by a brass guard ring. Fig. 294 shows the two discs and indicates the manner in which the rings are divided.

A section of the distributor top is given in Fig. 297. The front disc is shown on the left with the brushes removed, and the rear disc on the right with the brushes in position. Motion is obtained from the regulator axle gearing with the wheel R^1, which in turn gears with R^2; the latter is bolted to R^3, which is not fixed to the main spindle X.

Ordinarily, the brushes turn with R^2 and the axle X through a form of epicyclic gear, but when a correction current passes through the electromagnet E_1, the forward motion of the brushes is retarded.

CORRECTION.

One distributor is run slightly faster than the other and is corrected backward, or to run a little slower and to correct forward.

Fig. 298 shows a practical arrangement of the correcting currents. The upper line of segments represents the second ring joined to the keys of the keyboard, and the next ring is joined to the line which passes through the line ring at B, through the Keyboards to a relay and to earth. The displacement of the segments at B to the right represents the time occupied by the current in passing over the line. The relay repeats only the positive currents, sending them through the various non-polarized electromagnets of the receivers. All but one of the segments in the lower line are shorter than the others. The large one, which can be moved sideways, and is known as the movable contact, is connected to the correcting electromagnet of the distributor, whilst the short segments are connected to the various electromagnets of the receivers.

When no work is being done the only positive current leaving *A* is from 12, which is the correcting current. *B* remains idle until this current is repeated at regular intervals, usually every second revolution through the movable

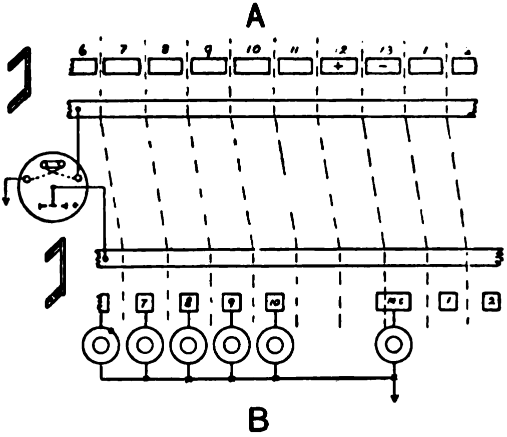


FIG. 298.—Correction current plan.

contact and the correcting electromagnet; *B* then knows that the current from *A* 1 will be received on *B* 1, and that from *A* 10 on *B* 10.

The object of the shortened segments is to cut out the uncertain portion of signals and to utilize only the full rise of current: it also prevents any overlapping of currents should there be a momentary change in speed of one of the distributors.

BAUDOT QUADRUPLE.

A skeleton diagram of the quadruple set is shown in Fig. 299. The two unbroken segments represent the fifth ring on the back plate of the distributors, whilst the dotted lines between them indicate the times occupied by the currents from the various keyboards which are connected to the rings immediately above and below. In both cases the Keyboards occupy the first twenty segments. The receivers at *B* take similar numbers, while those at *A* are two to the right, the time lost in propagation each way being equal to one segment. This adjustment is made by turning the front plate of the distributor while *B* is sending a positive current from the middle segment of his first keyboard. In this case it is 13 and signals the letter *Y* or figure 3. *A* turns his front disc until he receives this signal first on his receiving segment 12, and then on 14; he then halves the position between these two points and clamps the disc, thus obtaining the best possible position for reception, an equal margin of distortion being allowed in either direction.

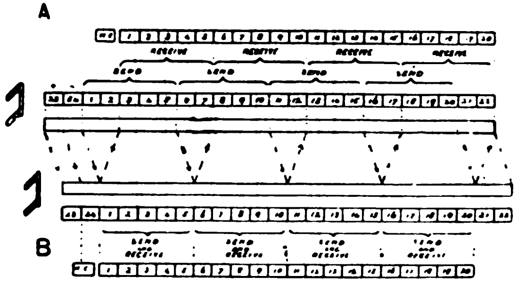
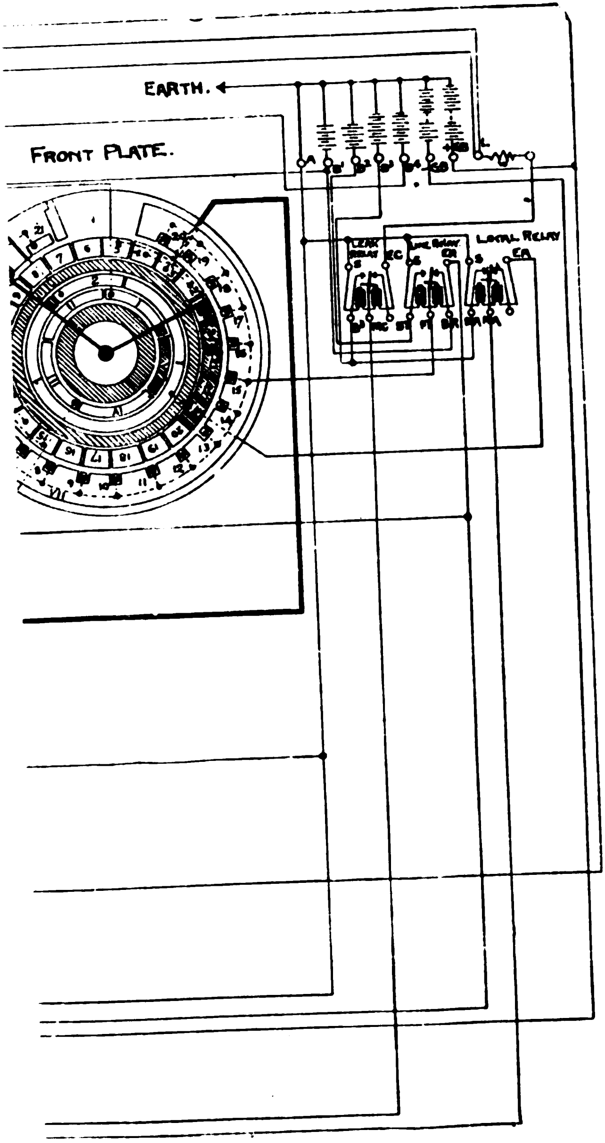


Fig. 299.—Quadruple set. Skeleton diagram.

The correction currents occupy segments 23 and 24, reaching the movable contact through a relay as already explained. As *A* sends out the correction currents his movable contact is not in use, it being obvious that corrections are not required in both directions.

The quadruple set is exceedingly flexible since it provides four channels over one wire, and each channel may serve in either direction.

The complete connections of one set are shown in Fig. 300. For convenience of illustration, the rear plate of the distributor is represented as having been turned through an angle of 180 degrees, and the brushes therefore rotate in opposite directions. As previously stated, the brush arms are spaced 120 degrees apart for mechanical


EARTH.
FRONT PLATE.
A
B1
B2
B3
B4
SB
+SB
L
LEAK RELAY
EC
S
LINE RELAY
ER
S
LOCAL RELAY
S
EA
MC
ST
FT
BR
BA
MA

reasons, and consequently segment 1 of each ring is dealt with similarly.

Commencing from the earthed batteries supplying the current to the keyboards and to the correction segments 23 and 24, it will be seen that the negative battery current reaches the back plates of the keyboards via the keyboard switches, whilst the positive goes direct to the front plates. Currents pass through the key levers of the sending keyboards to the various segments of ring 2, through the brushes to ring 5, and to the line terminal, where there are two paths—one through the switch and galvanometer to line and the distant station, the other through a high resistance and a relay, known as the leak relay, to earth. The leak relay repeats only the positive currents by battery B^3, the tongue of the relay and the switch of the particular keyboard, to one of the long segments of ring 4, and through the brushes to ring 1, the segments of which are connected to the electromagnets of the four receivers. The shaded portions of rings 1 and 4 are not used.

Before an operator can send he must know the precise moment to depress the keys. This is given him by the cadence or time-tapper electromagnet used for holding down the keys. The current is obtained from the battery B^4, connected to the complete ring 6 through the brushes to ring 3 and the second segment in advance of each keyboard. For instance, for keyboard 1 segment 23 is used, for keyboard 2 segment 4 is used, etc. Other segments of this ring 3 form the second contact point in the electric brake of the receivers. Segments 1, 2, 3 are connected together for this purpose and joined through the electromagnet of the brake in the receiver to the contact springs, which are closed once in each revolution.

The currents from line arrive via the galvanometer and switch to the line terminal, where they find a high resistance leak path to earth. If sufficient current should pass through the leak relay—which is not likely—no action can take place, as the tongue of the relay is disconnected at the switch of the receiving keyboard. The other path for the received currents is via ring 5 of the back plate, through the key levers to the back plate of the keyboard, through the key switch to the coils of the line relay and to earth.

The line relay repeats both the positive and negative currents, using batteries B^1 and B^2, and sending the currents to the ring of small segments on the front plate, known as ring 7. (This is not shown very clearly in the diagram—at first sight it looks as if the connections were made to the large outer toothed ring, which, however, is not electrically connected, but forms merely a support for the brush as it passes between the small segments.) The movable contact is connected to the small segments.

Ring 7 is connected by the brushes to ring 10, consisting of two unequal segments; the smaller one is connected to one side of the correcting electromagnet of the distributor, whilst the other side of the magnet is permanently connected to battery B^1. The other segment of ring 10 is connected to the coils of the local relay and to earth. The local relay, using battery B^3, repeats only the positive currents, which pass through the switches of the keyboards of the receiving channels to the segments of ring 11 (one to each keyboard), and thence through the brushes to the electromagnets of the receivers.

The correction currents always pass through the line relay and always actuate it; but when the two distributors are correct the positive repeated current is completed before the brush of ring 7 reaches the movable contact, and it therefore does not pass through the correcting electromagnet. The negative current will be on when the brush reaches the movable contact, but as the other side of the electromagnet is joined to the same negative battery no current can pass. When the positive current passes through the movable contact, the electro-magnet responds to the power of the two batteries B^1 and B^2 joined in series.

Fig. 301 will show more clearly the paths and actions of the different currents. One key of the first keyboard is shown: the currents pass from ring 2 to ring 5 and thence to line, a portion going through the leak, where only the positive currents are repeated, passing through the switch of the keyboard to rings 4 and 1 to the receiver.

The received currents pass from line to ring 5, thence by the brushes to ring 2, through the keyboard switches to the line relay and earth. The currents are repeated to ring 7. via the brushes to ring 10, thence to the local

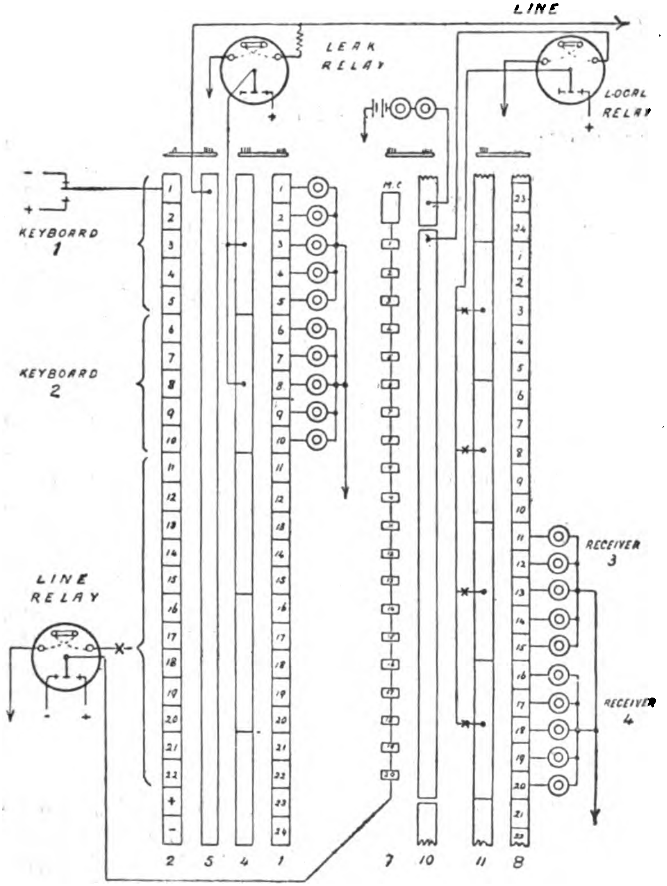


FIG. 301.—Skeleton connections of a Quadruple set.

relay and earth. The positive currents are repeated to ring 11, then via the Keyboard switches to ring 8 and the electromagnets of the receivers.

The correct setting of the brushes is highly important. All coupled or pairs of brushes are set with their ends on the same radius. The pairs in relation to each other are first set at exactly 120 degrees. Then those of rings 4 and 1 are set backward about one-quarter of a segment behind the 120 degrees mark, to allow for the time occupied by the outgoing currents in traversing the leak relay and sending out the local currents through the receiver magnets. The same applies to the brushes of the front plate, those of rings 8 and 11 being set about the same proportion behind those of rings 7 and 10. The corrected station receives on segments 1 to 10, and the brush on ring 2 is therefore set at the commencement of segment 11, the front plate being turned so that the brush on ring 7 is half a full contact past the centre of the tenth small contact. There is, of course, a limit to this movement because of the correcting electromagnet, which must act at a certain moment in relation to the movable contact, and on this account it is arranged that the position of the brush holder can be re-adjusted at the driving axle by angles of 30 degrees: there is therefore every facility of obtaining the required adjustments. The correcting station slews the whole of his front plate, *i. e.*, rings 7 to 12, till he obtains the third signal from the corrected station's sending keyboard on the third magnet of his corresponding receiver.

BAUDOT DUPLEX.

Like all other telegraph systems, the Baudot can be duplexed, that is to say, it is possible to work double, duplexed, giving four channels; triple, duplexed, giving six channels; quadruple, duplexed, giving eight channels; quintuple, duplexed, giving ten channels; or sextuple, duplexed, giving twelve channels.

The last arrangement is now in daily use in this country.

Fig. 302 shows a skeleton diagram of a Baudot duplex. The arrangement applies equally either to quadruple or to sextuple; the practical difference being merely in the number of segments allotted to the distributor rings and the number of keyboards and receivers provided.

One distributor at each end serves for the sending keyboards via the back plate; and for the receivers via the front plate. There is a distinct advantage in duplexing in that the segments allocated for propagation in a simplex are not required, therefore twenty-two segments instead of twenty-four are sufficient for a quadruple, giving an increase of 8% in the working margin.

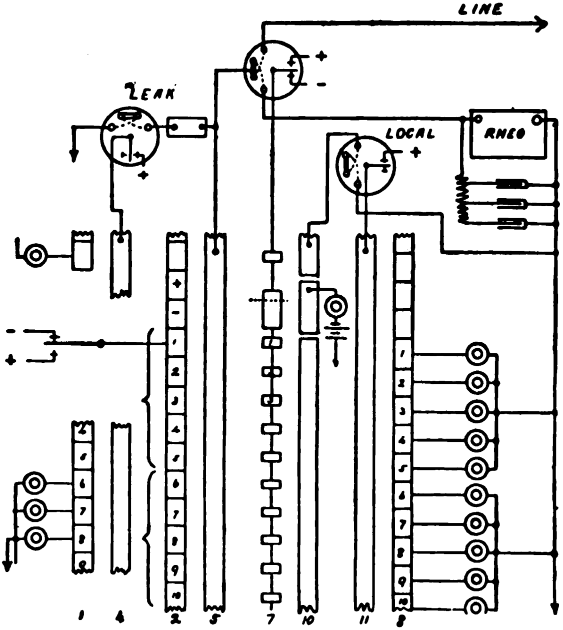


FIG. 302.—Skeleton plan for duplex working.

The path of the outgoing currents is from the keyboards to ring 2, through the brush to ring 5, where three paths are available—one through a high resistance and a leak relay for recording the outgoing signals; the second and third through the coils of the line relay, to line and the artificial line respectively.

The leak relay records the outgoing signals in the usual way by repeating only the positive currents, which pass through rings 4 and 1 to the receivers.

The incoming signals pass through the line relay, finding earth via rings 5 and 2 through the spacing or marking battery according to the segment of ring 2 on which the brush may be at the time.

The line relay repeats both positive and negative currents through rings 7 and 10 to the local relay, which repeats the positives through rings 11 and 8 to the receivers.

The two plates of the distributor are independent of each other as regards their relative positions, because currents are being sent out all the time; and it is, therefore, only necessary to turn the front plate until the segments come in phase with the received signals.

Keyboard Perforator and Transmitter.

To avoid the necessity of learning Baudot operating, Carpentier, of Paris, designed a perforator in which the keys were arranged as on a typewriter. The depression of any key caused square holes to be perforated in a paper tape corresponding to the respective five keys of the Baudot code. This tape, Fig. 303, was passed through a transmitter controlled by the cadence signal of the distributor thus passing the signals to the line without the necessity of the operator keeping to the cadence beat or knowing the code.

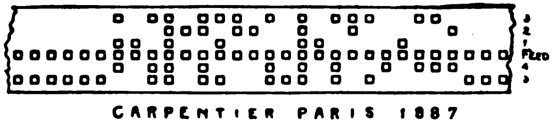


Fig. 303.—Carpentier slip for automatic working.

Cross-perforated tape has proved so successful in practice that manufacturers generally are turning their attention to the use of the Baudot code and Keyboard Perforators not only for main line working where several channels are obtained on one circuit, but also for minor line working where only one or two channels are required.

GENERAL.

All receivers in this country are driven by a small electric motor working by means of a twisted leather belt to a pulley on the type wheel axle instead of the old cumbersome weight drive.

The distributors are to a large extent driven by weights lifted by an electric motor, but in some cases these have been displaced by a distributor driven by a Phonic-wheel Motor and reed (*vide* Figs. 309 and 310). Direct motor drive to the axle of the Governor is also being tried among other arrangements. There is, therefore, every prospect of the weight driven Distributor disappearing entirely in the near future.

Owing to the scarcity of Baudot apparatus during the War period the local control was disused in order to allow the Receivers so released to be utilised to form other installations. This arrangement has now become standard, thereby considerably reducing the installation and maintenance costs.

The five unit code first successfully used as a Telegraph code by Baudot was allocated to the letters of the alphabet in a convenient order for easy learning, *i.e.*, Keys 1, 2 and 3 were allotted to the vowels, while the consonants were formed in alphabetical order by the combination of keys 4 and 5 to the vowels, thus verification of a letter is always an easy matter. Unfortunately this arrangement does not suit typewriter keyboards, hence the reallocation of the alphabet in the Western Union and Murray duplex multiplex systems.

CHAPTER XV

THE MURRAY AUTOMATIC AND MURRAY MULTIPLEX SYSTEMS.

PART I.—THE MURRAY AUTOMATIC SYSTEM.*

THE punched slip, prepared on typewriter keyboard perforators, is passed through the transmitter and thereby perforates a slip at the receiving end in precisely the same positions as the original or transmitting tape. The received tape is then passed through a translator which mechanically typewrites the message in page-form on specially prepared forms.

In the Murray system each letter is of precisely the same length and is transmitted by permutations of five units. There is no space between the various letters composing a word, and the currents may, and, in fact, do actually, run together. Moreover, the system is one which merely involves isochronism, and does not, as in the Delaney multiplex, necessitate synchronism; by which latter term is meant the identity of speed and phase between the motions of two bodies at a distance. Isochronism merely requires identity of speed; that is to say, two clocks would be isochronous if the hands move at the same speed, whereas they would only be synchronous if they indicated the same time at every instant. The term unison is employed to denote the method adopted for correctly dividing off or distinguishing groups of letter signals.

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* This description is taken from Mr. Donald Murray's paper, "Setting Type by Telegraph" (*Journal of the Proceedings of the Institution of Electrical Engineers*, part 172, vol. xxxiv.), by the permission of the Editing Committee and with the sanction of the Author.

The Murray may readily be duplexed upon the differential or bridge methods, the ordinary standard condensers and rheostats being used for this purpose.

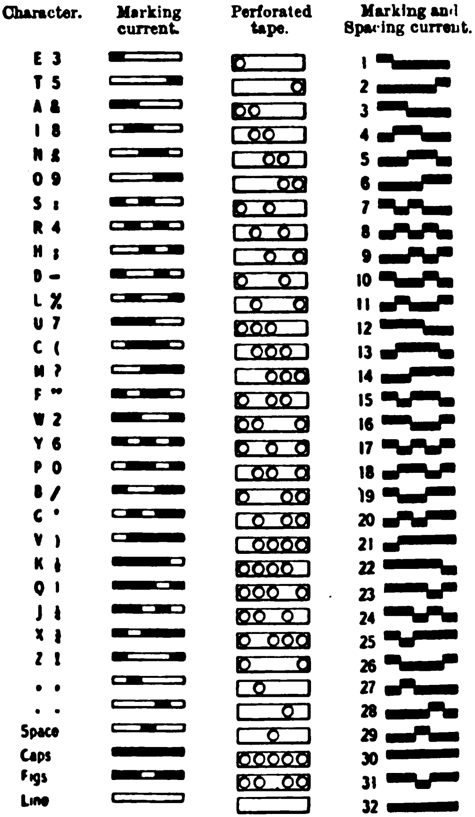

FIG. 304.—Murray Alphabet, 5 units per letter.

THE MURRAY TAPE, AND THE CORRECTION OF ERRORS.

Fig. 305 shows a piece of this tape perforated with holes representing the word "PARIS," while beneath it, on line

3, are shown the main-line time signals which this tape transmits, or which produce this tape at the receiving station. For the sake of clearness the main-line signals are shown as made up of positive and zero units. But it is preferable to use positive and negative units (double current), zero positions being filled with negative units. Each letter permutation occupies half an inch lengthwise of the tape, each letter space being divided up into five equal units. Any one or more of these units may be perforated with a message hole. This gives thirty-two permutations. Following the example of Hughes and Baudot, one

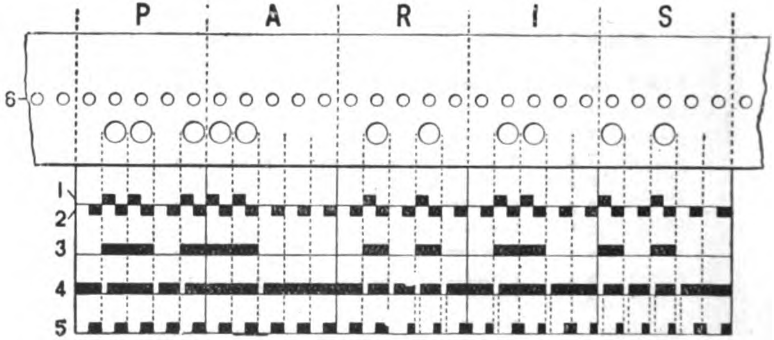

FIG. 305.—Isochronism diagram.

of these groups is used as a figure-shift and another as a letter-shift, and there are about fifty-two type characters. The central row of feed-holes in the tape 6, Fig. 305, is punched beforehand at an immense speed by pulling the tape through between a punch-wheel and a die-wheel.

In the Hughes and Baudot, errors and the succeeding corrections are cut out of the tape before it is pasted on the form, and there is then nothing to make the recipient uneasy about its accuracy. With a direct-transmitting page-printing telegraph this cannot be done. All automatic systems in which there is preparation of the message beforehand possess the potentiality of correcting an error before transmission. In the Wheatstone system, for instance, this process is known as a "rub-out." In automatic telegraph systems, in which a printing machine takes the place of the receiving operator, it is a comparatively simple matter to arrange that the printer shall imitate the action of the operator by remaining inactive when dots only are coming over the line. In this way no trace of the error appears in the printed message. With automatic systems like the Murray, using an alphabet in which the letter signals are all of the same length, the transmitting tape, while being prepared in the keyboard perforator, can be pulled back instantly letter by letter by depressing a lever. If an operator strikes a wrong key, all he has to do to rectify his error is to strike the back-spacing lever, the letter-shift key, and the desired letter—the work of a moment. A word of six letters can be blotted out in this way in a few seconds, and no trace of the correction, not even a blank space, will appear in the printed message at the other end of the line.

THE PERFORATOR.

A keyboard perforator is, of course, employed to prepare the perforated tape. The actual perforator consists of a punch block with five punches, and an electromagnet the armature of which, when attracted, moves the striker bar forward to the ends of the five punches, but its travel is limited to prevent the punches being struck. The punches are operated by the interposition of the flattened ends of five rods between the striker bar and the punches, the interposed metal forming an extension of the striker bar and thus causing the punches to be struck through the tape. Each key is provided with an arm having appropriate projections engaging and depressing selectively the six flat levers which run the whole length of the keyboard. Five of these levers serve to interpose the strips between the striker bar and the punch blocks, whilst the sixth closes the circuit of the electromagnet when the key is fully depressed. The front stroke of the electromagnet punches and the back stroke feeds the tape forward one letter space. A lever is provided for pulling the tape back letter by letter when a correction is necessary. The correction is made by striking the letter-shift key (Caps). This punches five holes in a letter space, and so blots out all other permutations which may have been previously punched. At the other end of the line this signal leaves the printer unaffected, its functions being to shift the action of the printer from figures to letters. The tape is divided off by printed cross-lines into letter spaces, and an operator can readily learn to read it.

TRANSMISSION.

The perforated tape, containing a batch of messages, having been prepared, the next step is automatic transmission.

The marking and spacing currents shown in the last column of Fig. 304 are transmitted in accordance with the relative positions of perforated and non-perforated units of the slip. The transmitter is driven by a phonic-wheel and reed, so as to secure the utmost uniformity of speed. The star-wheel 15 (Fig. 306) feeds the slip forward by means of the central row of holes past the reciprocating rod 1, which is kept in motion by the thrust lever 2 and the oscillating lever 3. The end 9 of this thrust-lever accordingly strikes the thrust-bars 10 or 11, depending upon whether the reciprocating rod meets blank paper or passes through a perforation respectively. In this way marking currents to correspond with the perforations are transmitted to line, the intervals between such currents being filled by spacing currents.

A vibrating reed 23 (Fig. 306) sends electrical impulses alternately to the two motor magnets 24 and 25, and these keep the notched armature 26 in steady rotation. This armature 26 drives the star-wheel 15 and eccentric wheel 5. The arrangement is in reality an electrical pendulum with the action reversed, the pendulum driving the escapement wheel, the two magnets being the two pallets of the escapement which pull the escapement wheel 26 round step by step, though the inertia of the wheel is sufficient to ensure uniform motion. The vibrating reed being isochronous in the acoustical sense, the speed of the motor is practically the same for all amplitudes of vibration—that is to say, variation of current strength has no

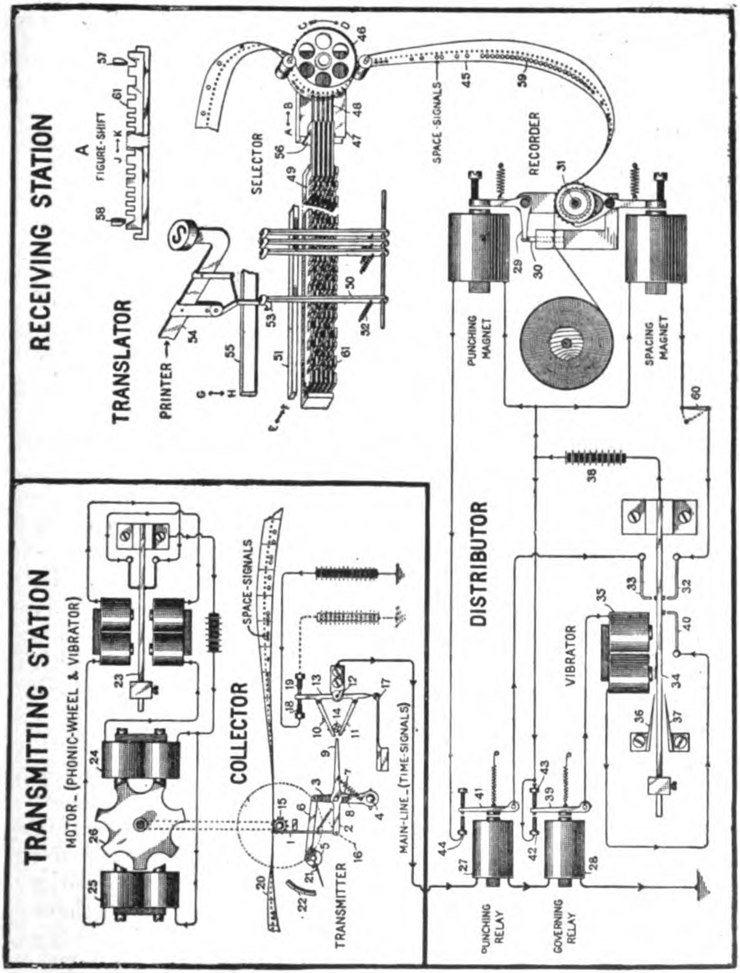

Fig. 806.—General diagram of Murray Automatic Printing Telegraph System.

serious effect on the speed of the motor, and the speed is, therefore, remarkably uniform.

The working and spacing currents shown in the last column of Fig. 304 are sent out to line by the action of the reciprocating rod in accordance with relative positions of the perforated and non-perforated units of the slip.

THE DISTRIBUTING MECHANISM.

The distributor at the receiving station consists of two relays, a vibrating reed and a recorder. In practice the main-line signals pass through an ordinary polarized relay to earth, this relay operating two local relays; but for the sake of clearness the main-line signals are shown passing direct through the two local relays 27 and 28, Fig. 306, to earth. It is by means of these two relays that the rest of the distributing mechanism is controlled. The recorder, which punches the message-holes in the receiving tape, is also shown in Fig. 306. This recorder consists of a punching magnet and a spacing magnet. The punching magnet operates a punching lever 29 and a punch 30. This punch corresponds with the small rod 1 in the transmitter. The punch reproduces the motions of the rod, and thereby reproduces the perforations in the tape. The spacing magnet feeds the tape forward unit by unit by means of the escapement and star-wheel on the motor-driven spindle 31. In order to secure the alternating action of these two magnets, the contacts which close their respective circuits are arranged one on each side, 32 and 33, of a vibrating reed 34, driven by a magnet 35. As the reed vibrates, short impulses are sent alternately to the punching and the spacing magnet. When there are no signals passing in the main line, a special device (not shown) cuts out the spacing magnet by opening the switch 60, and so stops the tape; but as long as a message is passing the vibratory action of the spacing magnet is continuous, and the tape is fed forward at a fixed speed. The punching magnet works alternately with the spacing magnet, but only when there is marking current in the main line, the punching relay 27 controlling the circuit of the punching magnet. The oscillations of the tongue of relay 27 and of the vibrating reed must therefore be not only isochronous, but also synchronous. Between sending station and receiving station isochronism only is needed, but between the receiving instruments on the same table synchronism is essential.

THE METHOD OF SECURING ISOCHRONISM.

The reed 34, kept vibrating by the magnet 35, beats against buffer springs 36 and 37. These limit the amplitude of vibration, and, as the energy imparted to the reed must find some outlet, the frequency is increased. Without buffer springs the amplitude of vibration varies in proportion to the strength of the current through the reed magnet, but the frequency is wonderfully uniform. The reed is then isochronous in the acoustical sense. With a fixed amplitude determined by the buffer springs the frequency varies with the strength of the current. The reed is no longer isochronous. Its speed becomes very sensitive to variations of current, and can therefore be controlled by controlling the current to the reed magnet. If the circuit of the reed magnet 35 is traced from the battery 38, it will be found that it has two break-points—one at the contact of the tongue 39 of the governing relay 28, and the other at the reed contact 40. The punching and governing relays are identical in all respects, and they are driven by the same power, so that their synchronism is perfect. The tongue 39, therefore, moves in exactly the same time as tongue 41. Hence as long as tongue 39 oscillates synchronously with the reed, tongue 41 will do the same—in fact, the two relays might be replaced by one relay with two tongues. The back and front stops, 42 and 43, of the governing relay are electrically united, so that at the beginning and end of a main-line signal when the tongue of the governing relay crosses from one contact to the other, there is a momentary break in the reed magnet circuit during the time of the transit of the tongue. This transit time can be varied to a considerable extent by adjusting the position of the contact stops. Opening the contacts increases the governing effect, and closing them diminishes it. The reed magnet 35 breaks its own circuit at 40 in the usual vibratory way. If the reed 34 is oscillating in synchronism with the relay tongue 39, then full vibratory impulses will flow through magnet 35, as the two contacts at 39 and 40 will be opened and closed simultaneously. But if the reed tends to go faster than the arriving signals, then the two contacts 39 and 40 no longer open and close together, but more or less alternately, and the current impulses in the magnet 35 are more or less clipped. This reduction in the supply of energy to the reed at once reduces its speed till the contacts are again simultaneous. In practice the receiving vibrator is set to run about 2 or 3 per cent. faster than the arriving signals, and the governing action of the two interfering break-points in the same circuit results in the establishment of a steady dynamic balance between the accelerating tendency of the reed and the retarding tendency of the arriving signals. The effect is exactly the same as that produced by two taps in a water-pipe. If both are opened and closed together the water flows through in gushes; but if they are opened and closed alternately no water gets through, and more or less water gets through accordingly as the taps are opened and closed more or less alternately. By this means the relay tongue 41 not only vibrates at the same speed as the reed 34, but preserves the same phase—that is to say, tongue 41 touches contact 44 at the same time as the reed touches contact 33, even when the reed is making seventy-five vibrations per second (150 words per minute). But the tongue 41 does not move for every vibration of the reed. For instance, if there is a 4-unit marking signal coming over the main line, then the tongue 41 closes on its punching contact 44 for an interval of 4 units' duration, and the reed then makes four vibrations, touching the contact 33 four times, and in this way punching four successive holes in the tape by the alternate actions of the punching and spacing magnets. The transit intervals of the tongue of the governing relay 28 might be said to be like the teeth of an old saw. Some are there and some are not, but such as remain are all at unitary distances from one another (see line 4, Fig. 305). So also with the signals, and there are always enough signals to govern. Actually one correction per letter is sufficient, but on the average there are not less than two and a half, because each main-line signal gives two corrections, one at the beginning and the other at the end of the signal.

The isochronism diagram, Fig. 305, illustrates the co-operation of the current impulses. It shows a section of receiving tape punched with the word "PARIS." Beneath are the current impulses, indicated by black bars. Line 1 shows the impulses given to the punching magnet by the successive contacts of the reed 34 with the contact 33. Line 2 shows the uninterrupted succession of impulses to the spacing magnet from the reed contact 32. Line 3 shows the main-line signals. This illustrates the great saving of line signals effected by the special arrangements of the collecting and distributing mechanisms. Without these special arrangements it would be necessary to transmit over the main line the signals shown in lines 1 and 2, that is to say, about five times as many signals as are now required. Line 4 shows the gaps in the circuit of the reed magnet 35 made by the crossing from contact to contact of the tongue 39 of the governing relay. Line 5 shows the impulses generated by the reed contact 40. As long as these impulses do not get into step with the gaps in line 4 they are not interfered with; but directly they do they get clipped, as shown for the sake of illustration in the second half of line 4. The speed at the two stations can, of course, be varied by altering the position and size of the weights on the vibrating reeds at the two stations.

The speed of working is from 100 to 180 words (600 to 1080 letters) per minute. The received slip may either be used to retransmit the message on any other Murray circuit or it may be passed through the translator or printer which typewrites the message in Roman characters.

THE SECOND TRANSLATION AND PRINTING.

The essential features of the Murray printer are shown in the general diagram, Fig. 306. The tape is fed along letter by letter (five units at a time) by a star-wheel 46, carried on a shuttle 47, which is kept reciprocating in the direction shown by the double arrow *A-B*, by means of a cam, each reciprocation rotating the star-wheel one letter space as shown by the arrow *C-D*. The shuttle carries a die-plate coinciding with the circumference of the star-wheel, and having five holes corresponding with the message-holes in the tape. Five rods 48, fixed in the ends of five slotted combs 49, are free to enter the five holes in the die-plate if they are not obstructed by the paper tape which passes between the rods and the die-plate. On its inward stroke the shuttle with its die-plate presses the tape, with a letter group of perforations, against the ends of the five rods 48. Rods that are opposite holes in the tape pass through into the die-plate, and the positions of the corresponding combs are not altered. But in the case of non-perforated units of tape the corresponding combs are thrust back about $\frac{1}{16}$th of an inch. By this means one particular group of slots in the combs, and only one out of fifty-six is brought into alignment so that a latch or cross-bar 50 can drop into it. Although only four latches are shown, there are fifty-six of these small levers, one for each of the fifty-six permutations or groups of slots. The latches or cross-bars are supported by a universal bar 51 just clear of the teeth of the combs. At the right moment this bar drops in the direction of the double arrow *F*-*E* and leaves all the cross-bars resting on the combs; but only one out of the fifty-six is selected by the particular aligned group of slots corresponding to any particular group of holes in the tape.

Although in the Murray printer there are only five combs with rods 48, there is a sixth comb 61, which in one position causes figures to be selected and in the other position letters. It is operated by two special cross-bars, one each end. This arrangement is shown more clearly at *A*, Fig. 306. At each end of this comb will be noticed a V-shaped slot, and the two cross-bars shown in section at 57 and 58 carry wedge-shaped pieces for striking the edge of these V-shaped slots. When a figure-shift signal is transmitted, it selects the figure cross-bar 58. This drops into its group of slots, strikes against the sloping edge of the figure-comb slot, and moves the comb $\frac{1}{16}$th of an inch to the left in the direction *J*, thereby opening the figure-locks and closing the letter-locks. A letter-shift signal succeeding a group of figures operates 57, which restores the figure-comb to its original position, in which the machine prints letters. If the letter-shift signal, ooooo (Caps), is repeated, no further action takes place, and the printer remains idle till a letter signal comes along. Thus, in the tape at 59, Fig. 306, there is a correction consisting of five letter-shift signals, which have been used to "rub out" a wrong word of five letters. For the reason just given the printer remains idle during these five letter spaces, and there is no trace of the error in the printed message.

In order to divide up the signals properly we have to start at the right unit and then measure 5 units at a time, and this is readily arranged with the aid of a simple mechanism.

Any good typewriter may be employed in the printer. Murray made a special high-speed typewriter for the purpose, with ball-bearing type-bars only two inches long. The maximum speed was 1200 letters (200 words) per minute; but it was found that there was great wear and tear at such high speeds, and as the special field for the Murray automatic is on very long aerial lines, 2000 miles or more, where the speed is of necessity low, an ordinary commercial typewriter is now used.

PART II.—THE MURRAY MULTIPLEX.

The Murray multiplex was developed as a combination of the best features of the Baudot multiplex and the Murray automatic systems. It is, however, essentially a multiplex system, and careful study of the description of the Baudot multiplex already given will render it easy to understand the following description of the Murray multiplex. The distributor divides the line time between 2, 3, 4, 5 or 6 operators precisely as in the Baudot, but instead of the familiar five-key sender, a Murray keyboard perforator is used to prepare a slip which passes through a simple form of transmitter. The Murray automatic keyboard perforator produced slip with the perforations arranged lengthways, as may be seen by inspection of Fig. 306.

The perforator producing lengthways perforated tape has been used by the Post Office for about seven years on the Murray multiplex London-Manchester circuit; but cross-perforated tape, as shown in Fig. 307, has such great advantages for multiplex work, that the improved Murray multiplex keyboard perforator produces slip with the letter perforations arranged across the tape (see Fig. 307). On this slip a message of 20 words (120 letters) is only 12 inches long. The economy of tape is also great, running to as much as 70% compared with automatic slip. Inspection of Fig. 307 will show that the central feed-holes, third row from the top, are set slightly in advance of the message holes, and this shows instantly which is the beginning and end of any piece of slip, no matter how small it may be. This facilitates the handling of retransmission slip and also slip for multiplex news distribution.

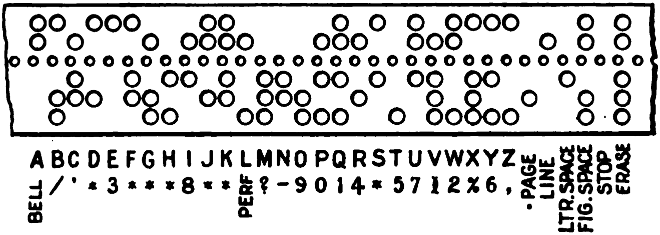
A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
BELL / ' * 3 * * * 8 * * PERF ? - 9 0 1 4 * 5 7 1 2 % 6 , • PAGE LINE LTR. SPACE FIG. SPACE STOP ERASE

FIG. 307. – Cross-perforated tape of alphabet A–Z.
Letters in first row are primary characters. Figures in second row are secondary characters printed by prefixing "Fig. Space" signal. Words indicate operations. Seven stars indicate secondary characters which may be varied to suit requirements. Note that centre holes have lead to left to indicate beginning and end of tape.

At the distant end the message is page-printed direct from the line signals on ordinary message forms, but by means of a special signal the sender may switch in a receiving perforator which reproduces the Murray cross-perforated tape, thus enabling a transmitted message to be retransmitted on another circuit without transcription. The distributors are of the Baudot pattern, but are driven by a phonic wheel motor and vibrator. Distributors are really *clocks*, and in the Murray multiplex clock-making experience has been followed, the hands (contact arms) being shifted to correct the time or "phase," and a pendulum and escapement being used to control the "speed." The ordinary method of correction in a Baudot distributor is a shift-the-hands device, and the phonic wheel and vibrating reed are in reality an electric escapement and pendulum.

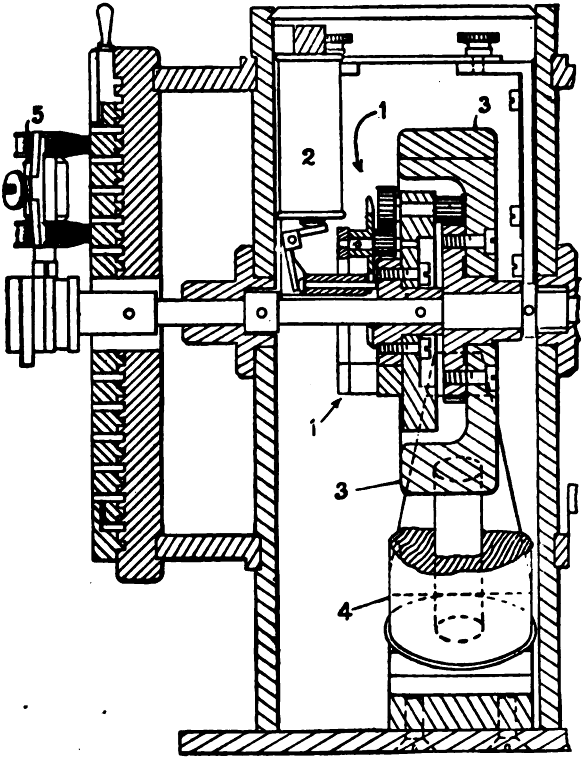

Fig. 306.—Distributor: sectional side elevation.

The Murray multiplex printing telegraph divides up the line time so as to give several transmissions or channels on one telegraph wire, each at a comparatively low speed, about 45 words a minute, suitable for the work of one operator sending and one receiving. Two distributors, identical in design, are employed, one at each end of the telegraph line (station *A* and station *B*). The distributor at station *A* sends out a governing impulse once for each revolution of the contact arm (four revolutions per second for 40 words a minute). This impulse controls the phase of the distributor at station *B* so as to keep it running in synchronism with the arriving signals at station *B*. The distributor used in the Murray multiplex is shown in Figs. 308, 309 and 310.

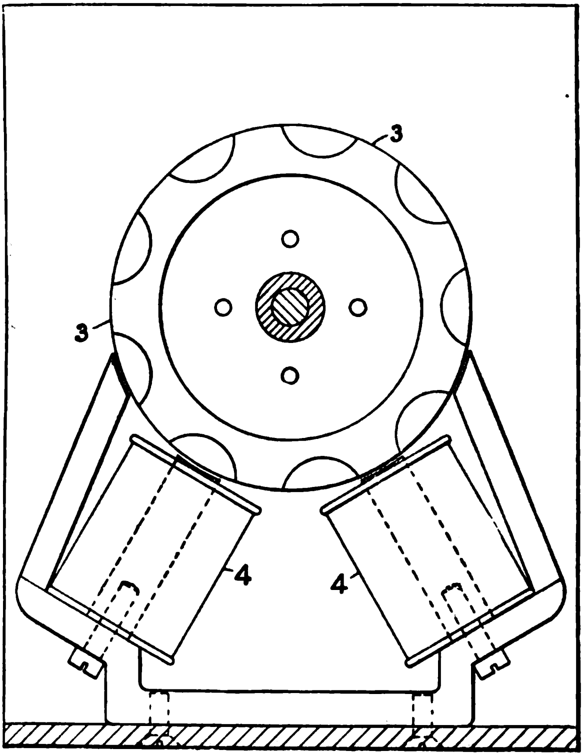

Fig. 309.—Distributor: front elevation.

Fig. 308 shows the Baudot distributor or clock with the usual "shift-the-hands" correction driven by the phonic wheel motor. 1 is the "shift-the-hands" correcting mechanism. The correcting impulse energizes the correcting magnet 2 which controls the correcting mechanism, causing it to shift the brushes or hands of the distributor a very slight amount, about 1½ degrees, for each correcting impulse. A correcting signal is transmitted from the distant station for each revolution of the hands, but it only operates the magnet when the departure from synchronism exceeds a certain very small amount. 3 is the phonic wheel, and 4—4 are the two magnets driving the phonic wheel. 5 is one of the brushes or hands of the distributor. Fig. 310 shows the vibrator 6 and its wire connections with the phonic wheel magnets 4.

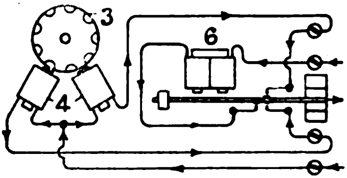

FIG. 310.—Connections of phonic wheel motor and vibrator.

The distributor brush arms are carried directly on the same spindle as the phonic wheel driven by the vibrating reed 6. The commutator and contact arms and brushes are the same as in the Baudot, and the adjustments are similar. This distributor will work perfectly in conjunction with Baudot printers and other Baudot apparatus.

The theoretical arrangement of the electrical connections in the Murray multiplex is shown in Fig. 311.

One of the transmitting channels or segments of the distributor and revolving contact brush are shown at each station. For the sake of clearness the other segments for the other transmissions on the same telegraph line are omitted, and for the sake of simplicity the Baudot 5-key transmitter is shown at station *A*, but these five keys may also be regarded as the five contact levers of the multiplex tape transmitter operated by the transmitter magnet, which corresponds to the cadence magnet of the Baudot. Also at stations *A* and *B* the vibrator and phonic wheel that keep the contact brushes of the distributor revolving are omitted. The five transmitting keys at station *A* normally rest against the top contact bar, which is connected to the negative end of a battery. The depression of any key breaks contact with the negative bar and puts the key into contact with the positive battery bar. The keys are connected to the contact blocks 1, 2, 3, 4, 5 of the distributor. Various permutations of five positive and negative impulses are transmitted into the line as the distributor arm revolves.

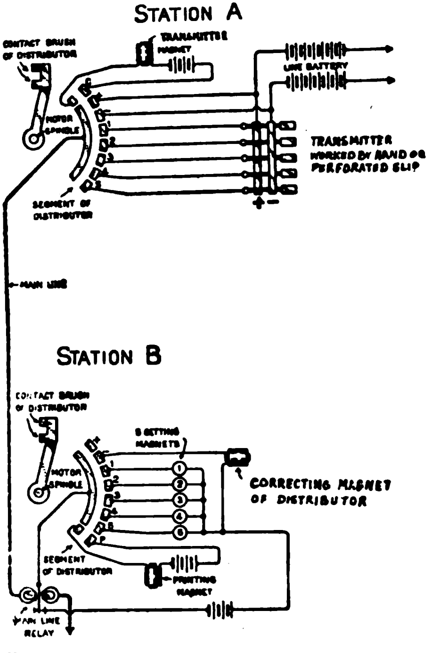

FIG. 311.—Theoretical diagram of Murray multiplex.

A typewriter keyboard mechanism to operate these five contact levers or keys so as to transmit direct to the line is provided, but practical experience has shown that perforated slip transmission is more efficient and easier for the operator.

The instruments used in the Murray multiplex for tape transmission are shown in Fig. 312.

The tape-feeding mechanism of the tape transmitter is operated at regular intervals—four and a half times a second—by the cadence contact on the distributor. This is equivalent to a speed of 45 words a minute.

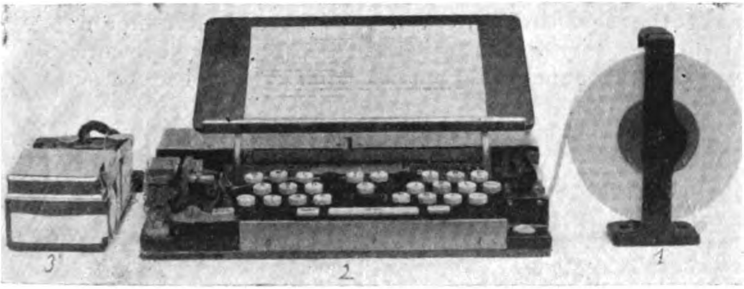

Fig. 312.—Tape-roll holder, keyboard perforator, and tape transmitter.

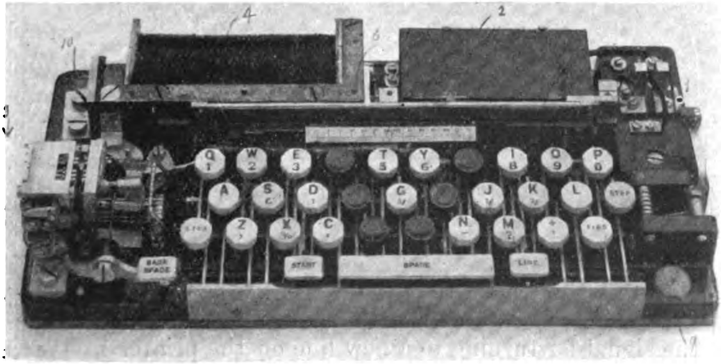

Fig. 313.—Cross-tape keyboard perforator (cover removed).

The tape-holder is shown on the right and the transmitter on the left of the keyboard perforator (Fig. 312). It will be seen that the tape is perforated at the extreme left-hand end of the machine, and that the transmitter transmits at its extreme right-hand side. Hence the distance between perforation and transmission can, if desired, be reduced to 6 letters—but 12 to 18 letters, corresponding to 3 or 4 seconds' delay between perforation and transmission, is a more convenient distance. A view of the keyboard perforator with the cover removed is given in Fig. 313, in which can be seen the keyboard in front, the punch-block, punch-hammer and back-spacing lever on the left, the electric contact on the right, and the punching magnet and a spark condenser at the back. Between the keyboard and the magnet may be seen the letter-counting mechanism to determine the time to send the signal for turning to a new line on the printer at the distant station (Fig. 314). A device (Figs. 315 and 316) has been added, whereby the transmitter stops automatically when it has transmitted up to within 12 letters of the last letter perforated, and starts again automatically as soon as more tape is perforated. This is a matter of considerable practical importance, as it enables

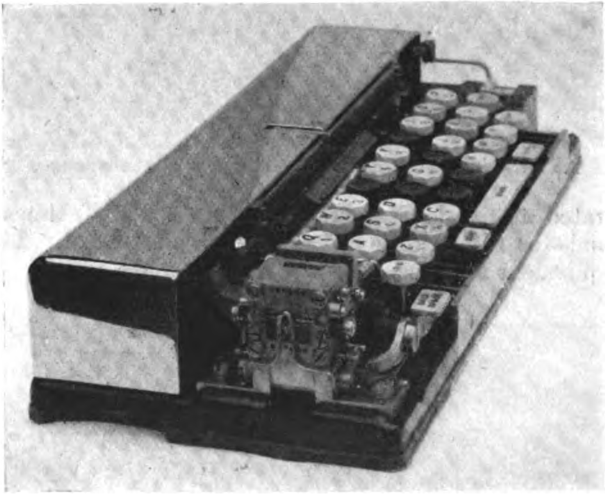

FIG. 314.—Cross-tape keyboard perforator.

transmission to follow close up to perforation without attention or worry on the part of the operator. Close-up transmission means quick R.Q.'s and reduced delay on traffic. This automatic start and stop is so arranged

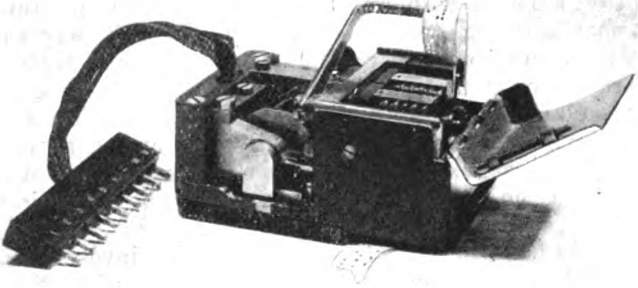

FIG. 315.—Tape transmitter.

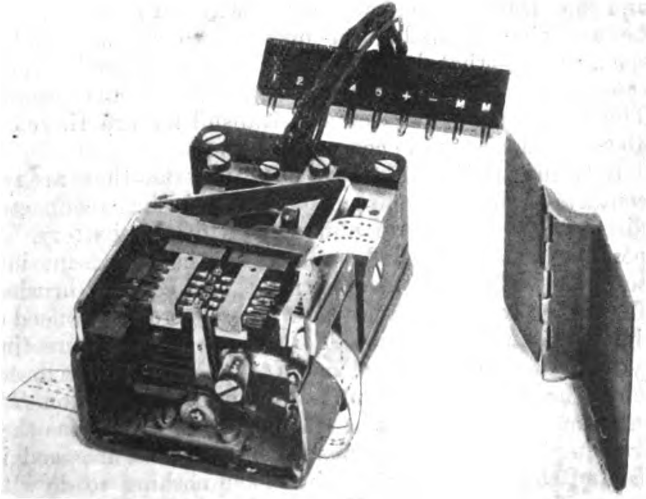

FIG. 316.—Front view of transmitter (cover removed).

that it only operates between the transmission of signals; otherwise signals would be mutilated. It also stops on the negative or non-operative contact, because otherwise signals would go to line after the transmitter stopped, with resulting errors in the printing. It may also be operated manually. In this way the operator has complete control over the tape. He can start or stop transmission at will. He can pull back the tape and repeat a message. He can correct errors instantly and invisibly. He has a perfectly free and extremely rapid typewriter keyboard, which he can operate as fast or as slow as he pleases. Only typewriter skill is required, and there is no cadence to be observed.

It will be noticed that tape transmission involves considerable increase in capital cost compared with direct transmission, and it also involves cost for paper tape, but the saving in time and labour is so great that it far outweighs the increased expenditure. Also, if a perforator and tape transmission are not used, then a printer has to be available to enable the operator to see what he is sending out—that is, to supply a "home record." With tape transmission the tape serves as the "home record." The cost of the perforator and transmitter are therefore about balanced by the cost of a printer.

Returning to Fig. 311, it will be noticed that there are two contacts on the distributor at station *A* which are connected direct to the plus and minus poles of the battery. A positive and a negative impulse are therefore sent into the line with each revolution of the contact brushes. This is the correcting impulse which controls the speed of the distributor at station *B*. The method of correcting synchronism is the same as in the Baudot distributor (shift-the-hands correction). The vibrator at station *B* is the same as the vibrator at station *A*. In both cases they are simply clock pendulums to secure uniform speed in driving the distributors. They have nothing to do with the mechanism for correcting synchronism, and the vibrators and phonic wheels are therefore omitted from the diagram. Let us assume that the contact brushes at the two stations are revolving at the same speed and that they are in phase with each other. Then, when the brush at station *A* is on the plus contact of the distributor, the brush at station *B* will be on the positive contact of the distributor at station *B*. A positive impulse will flow into the line at station *A* and will operate the main line relay at station *B*, closing the relay contact; but there will be no local action in consequence of this at station *B*, because the plus contact on the distributor is an idle contact with no connection. It will be seen that there is a local battery and a circuit passing through a magnet described as the "correcting magnet of distributor." (See also distributor diagram, Fig. 308, where this correcting magnet is marked 2.) When the two brushes at the two stations reach the two negative contacts on the two distributors the main line relay contact will be opened, and there will be no local action at station *B*. If now the vibrator at station *B* is adjusted to run ¼ or ½% faster than the vibrator at station *A*, then the rotating brush of the distributor at station *B* will run ¼ or ½% faster than the brush at station *A*. Hence when the brush at station *A* is on the plus contact, so that the main line relay contact at station *B* is closed, the brush of the distributor at station *B* will have reached the minus contact. The result will be that the local circuit through the correcting magnet will be closed and the magnet will then cause the "shift-the-brush" mechanism in the distributor to operate so as to shift the brushes (hands of the clock) back one or two degrees at each revolution, if correcting is necessary. In this way the correcting impulse from station *A* will repeat its retarding influence four times a second on the brush at station *B*, and in this way the two brushes at stations *A* and *B* are kept revolving not only at the same speed but also in phase, so that when the brush at station *A* touches successively contacts 1, 2, 3, 4, 5, the brush at station *B* will also be touching successively contacts 1, 2, 3, 4, 5 on the distributor at station *B*. Any permutation of signals sent out from the keyboard at station *A* will therefore be exactly reproduced in the five setting magnets of the printer at station *B*.

In the case of a double duplex installation working on a long and difficult circuit, such, for instance, as that across the Mediterranean, about 500 miles of cable between Marseilles and Algiers, the two extra correcting segments, in addition to ten segments for letters, represent 20 % of extra signals. It is desirable in such circumstances to avoid this loss, and for this purpose arrangements are made to get the corrections from the letter signals themselves. The mechanism is then a little more complicated, but the general principle of shift-the-brush correction remains the same. Donald Murray invented an arrangement for correction from the signals themselves for his multiplex in 1903, but up to the present there has been no occasion to use it, as most land lines can carry more traffic than there is available. A still earlier proposal of the same kind was made by a French inventor for a multiplex Hughes system, and the Baudot between Paris and Algiers has for some years been operated by corrections from the signals themselves. The Western

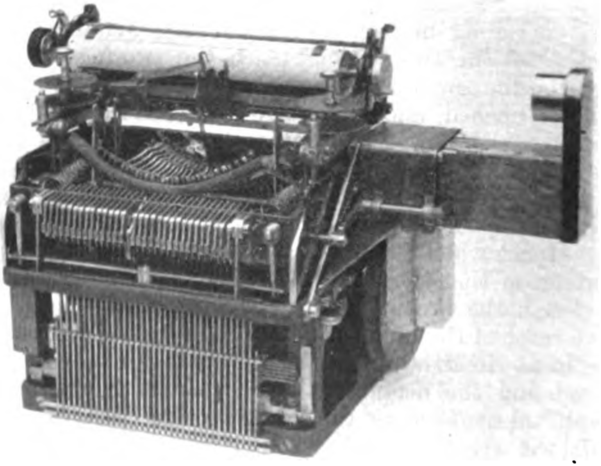

Fig. 317.—Front view of printer.

Union is also using this arrangement, but its utility is doubtful except in special cases like the Mediterranean circuit already referred to.*

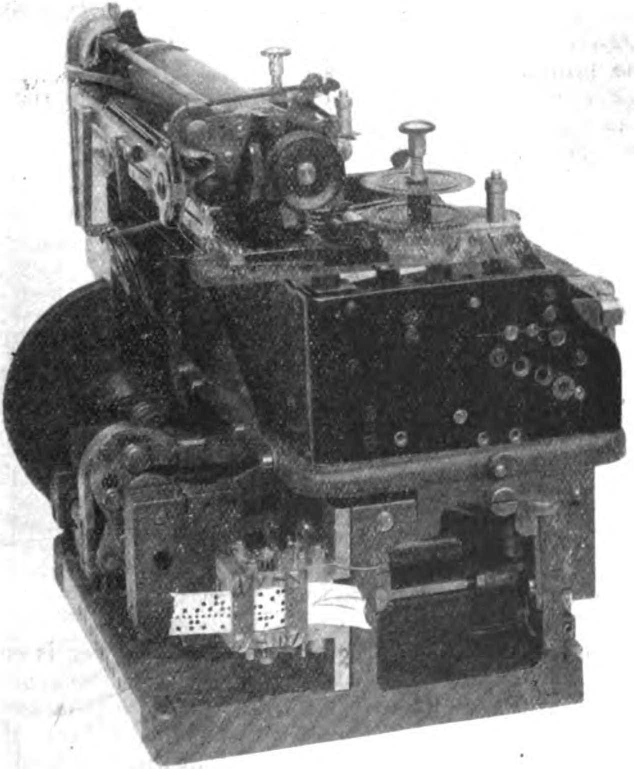

Fig. 318.—End view of printer.

The printer, of which there is one for each channel or transmission of the multiplex, is shown in Figs. 317 and 318.

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* Those who wish to study the matter more closely will find it described on pages 267 to 271 of *Le Télégraphe Multiple Baudot*, par Caminade et Naud.

Fig. 319 is a plan diagram; Fig. 320 a sectional elevation of the selecting mechanism with the typewriter removed, and Fig. 321 is a plan of one of the five setting magnets and the comb that it controls. The printer is driven by a small $\frac{1}{16}$-h.p. motor. As the printer will print correctly as long as it is driven faster than the distributor, there is no need for synchronism between the printer and distributor, the former being arranged to run anywhere about 20 or 30% faster than the latter.

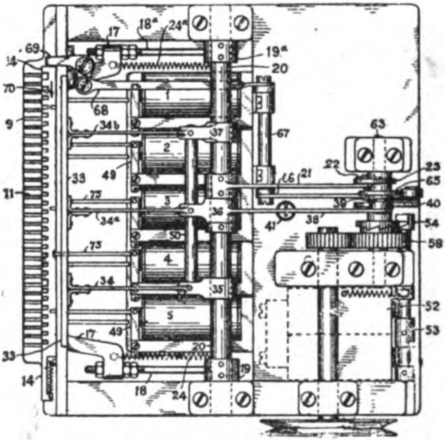

Fig. 319.—Murray multiplex printer: plan view with typewriter removed.

A small specially constructed typebar typewriter is employed, being arranged on top of the selecting mechanism of the printer shown in Fig. 320. Ordinary cut message forms of any administration are used, being fed into the printer automatically by mechanism that will be described presently. The result of this automatic page-printing mechanism is that the operator can devote his whole time to checking messages and RQs, and when everything is running well he can check up to 150 messages an hour, or has time to assist the sending operator.

In the diagram Fig. 311, at station *B* there are five small setting magnets, 1, 2, 3, 4, 5. These are in the printer, and they record the signals transmitted from station *A*. A plan view of one of these five setting magnets of the printer is shown in Fig. 321: 5 is the magnet coil, 72 is the yoke, and 49 is the armature, pivoted at 48 and retracted by the spring 76 against the back stop 74. At the free end of the armature there is pivoted a pawl 75, which passes through a slot 71 in the frame of the machine. Resting against this frame are five differentially slotted "combs," or metal strips, lying side by side. One is shown at 14. Each of the five setting magnets controls one of the five combs, the pawl 75 of each magnet engaging in a nick on the inner edge of its corresponding comb. Five springs 73 tend to move each comb $\frac{1}{16}$ in. (1·6 mm.) to the left. When a signal energizes one or more of the five setting magnets, the armatures are attracted and the pawls 75 are pulled back out of the way of the combs, which then move suddenly to the left in the direction of the arrow 83, under the action of their springs 73. In this way any given signal is stored up in the printer. Referring to Figs. 319 and 320, the five combs are shown in section at 14 in Fig. 320, and the top comb is seen in plan at 14 in Fig. 319.

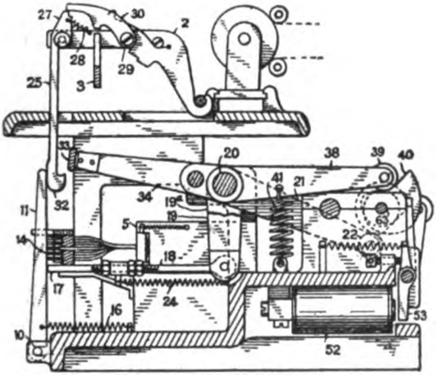

FIG. 320.—Murray multiplex printer: sectional elevation.

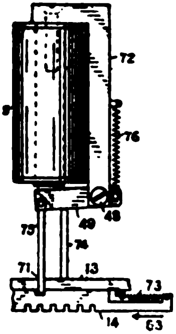

FIG. 321.—Plan of setting magnet.

Pivoted at 10 and crossing the combs at right angles are a series of about thirty latches or crossbars 11. These are held just clear of the combs by the supporting bar 17. Underneath the printer is a printing magnet 52. Referring to the diagram Fig. 311, it will be seen that this printing magnet is energized by the brush arm of the distributor closing a local battery circuit through the printing magnet immediately after the setting magnets have set the combs in some particular permutation representing a particular letter. In practice the printing contact is placed on an inner ring of the distributor, but for the sake of simplicity it is shown in the theoretical diagram in the same ring as the letter-setting contacts. The printing magnet, being energized, attracts its armature 53, which moves out the pawl 54, Fig. 319, thereby tripping a single-revolution clutch. This clutch, on being tripped, connects a constantly running pinion 58 (driven by the $\frac{1}{16}$-h.p. motor) with a cam spindle 63, carrying a battery of three cams. The clutch on being tripped causes the cam spindle to make one complete revolution, the clutch being then thrown out ready for the next printing impulse.

Referring to Figs. 319 and 320, it will be seen that the supporting bar 17 is carried at both ends by two connecting rods 18 and 18*a*, connected to two vertical levers 19 and 19*a*. These levers are pinned to the shaft 20. Pinned to the same shaft is a lever 21 with a cam roller 22. This engages with cam 23, Fig. 319. At the right moment, just after the combs have been set by the setting magnets, 1, 2, 3, 4, 5, the cam 23 (set in motion by the printing magnet) allows the lever 21 to rise slightly, thereby pulling in the supporting bar 17 by means of the springs 24 and 24*a*. This allows the crossbars 11 to rest against the combs, the crossbars being pulled inwards by springs 16, Fig. 320. For any given signal only one group of slots will be in alignment across the five combs, and into this group of aligned slots in the combs one particular crossbar drops forward and throws the hook 32 of the hook lever 25 under the universal striking bar 33. These hook levers swing on a pivot on each typewriter key lever 2. The top of the hook lever

27 is prolonged into a catch. On each key lever 2 there is pivoted at 29 a pawl 30. The free end of this pawl rests normally on top of the catch 27 of the hook levers 25. When any given lever 25 is swung inwards by a crossbar, the pawl 30 drops down at the back of the catch on top of the hook lever 25 and holds the hook in the inward position under the striking bar. The letter signal from the distant station has thus been transferred from the magnets to the combs, from the combs to the crossbars, and from the crossbars to one of the hook levers 25 hanging on a particular key of the typewriter.

The striker bar 33 is carried on the end of the three levers 34, 34*a*, 34*b*. These levers are braced into one frame by being pinned to the shaft 50, and they are free to oscillate on the shaft 20 by their hubs 35, 36, 37. From the central hub 36 there extends a lever 38 with the cam roller 39, which is operated by the snail cam 40 on the cam spindle 63. At the right moment this cam raises the lever 38 and depresses the striker bar 33, the striker bar frame oscillating on shaft 20, Fig. 320. The striker bar in its descent engages with the selected hook 32, thereby depressing key lever 2, and printing the corresponding letter on the typewriter. As the key lever 2 descends, the pawl 30 strikes the slotted bar 3, and is thrown out of engagement with the hook lever 25, which is then free to be restored to its normal outward position by the spring 28 as soon as it is free from the striker bar 33, which is restored to its upper position at the end of each stroke by the spring 41.

The moment a crossbar has thrown a particular hook lever 25 forward into locked position, the supporting bar cam 23, Fig. 319, thrusts the supporting bar 17 forward so as to push out the crossbars, thereby freeing the combs. The moment this happens the combs are restored to their zero position by a third cam 65 on the cam spindle. This cam, by means of a chain of levers and shafts, 66, 67, and 68, causes lever 69 at the end of the combs to thrust the combs back in the direction of the arrow 70 to zero position, where they are instantly caught and retained by the magnet armature pawls 75. It will be seen on studying this chain of mechanisms, that the combs can be and are restored to zero position before the depression of hook 32—that is to say, before the printing commences. The result of this is that the setting of the next letter signal by the setting magnets can proceed simultaneously with the printing of the last selected letter. These actions being simultaneous, a more moderate rate of operation is possible for the same speed than would be possible if the actions were successive. This considerably reduces the noise and wear of the mechanism.

The printing does not require description, as any ordinary typewriter action answers the purpose.

The line and column feeds of the message form are effected in the same way as in the Murray automatic printer. There is a clutch, which is tripped at the right moment so as to connect with the driving power. This winds up a cord, which pulls the typewriter carriage back to the beginning of the line (line feed), and at the same time turns it up to a new line (column feed). The typewriter carriage itself throws out the clutch when it reaches the beginning of the new line. This action is extremely simple and rapid, and gives no trouble. The typewriter carriage returns to the beginning of a new line in the time of two letters—that is to say, in half a second. The time consumed in this way is therefore trifling.

The page up of the message forms is effected by rotating the typewriter platen through a fixed distance up to the starting-point of a new message. This is effected by a chain of gears and a single revolution clutch. A particular signal for paging up operates one of the crossbars, and this by suitable intermediate mechanisms trips the clutch so as to page up at the right moment. This paging up to a new message form is also very rapid, taking place in the time of two letters, or half a second. This is not counting the paging-up signal. Including the time of this signal, the time of paging up is three-quarters of a second. Page-printing in this machine, therefore, involves only trifling loss of time—on the average not more than 1½ seconds per message, and it saves gumming a tape-printed message on to message forms, the process employed in the case of the Hughes, the Baudot, and other tape-printing telegraphs.

CUT PAGE FEED FOR THE MULTIPLEX PRINTER.

Reference has been made to the fact that the Murray multiplex printer uses ordinary cut message forms of any telegraph administration, an automatic feeding mechanism being provided for the purpose. This is a unique feature possessed by no other printing telegraph, and the mechanism by which it is achieved is simple and positive. There are many rubber and suction devices used in the arts for feeding separate sheets of paper from a pile. Printing presses and cyclostyle machines are so provided. In the case of such machines, however, the same thing is being printed over and over again. Hence if the feeding mechanism fails to pick up a sheet occasionally no harm is done. In a printing telegraph, however, a failure to feed a message form would mean a message lost and an RQ and trouble. The feed must be positive, and it is for this reason that printing telegraph inventors have adhered up to the present to printing messages on continuous rolls of paper, or have fed in cut forms by hand. The new cut page feed for the Murray multiplex has been tried by the British Post Office on traffic for a month, and has been found to work well. It will be more easily understood from the following diagrammatic sketches than from photographs. The essential feature of the invention is taking ordinary message forms of any administration and punching a small hole at the middle of the lower edge, and several, preferably three, fairly large holes near the top of the form. The holes at the top are punched alternately a quarter of an inch to the right and to the left, and the message forms are piled up so that every second form has the holes to the right and the others to the left. Fig. 322 shows a Post Office telegraph form perforated in the way described with three large holes at the top and one small hole in the middle close to the bottom edge. The dotted circles at the top show the positions of the holes on the message form immediately below the one in the illustration. Fig. 323 is a diagrammatic side elevation of the page-feed mechanism, and Fig. 324 is a plan view. The pile of message forms 1, perforated as shown in Fig. 322, are laid on a tray 2, so

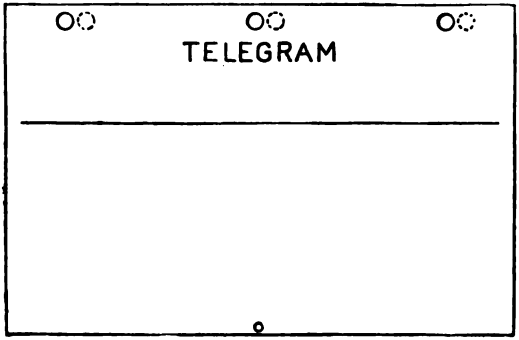

Fig. 322.—Cut page feed.

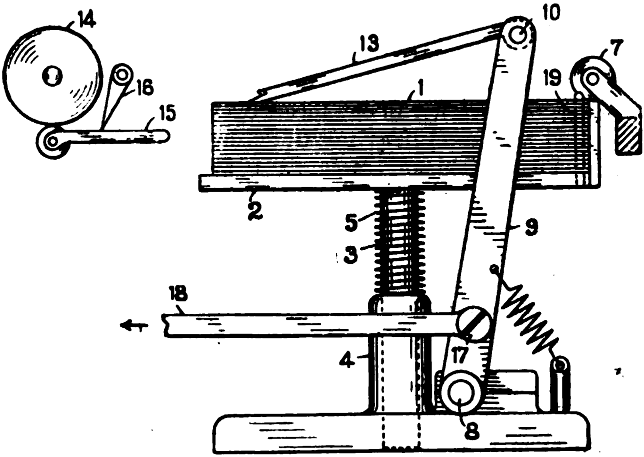

Fig. 323.—Cut page feed: diagrammatic side elevation.

that the vertical pin 19 fixed in the tray goes through the small hole in the message forms and serves to hold them in position. The tray is supported by a cylinder 3 free to rise and fall in a socket 4. The tray 2 with its attached cylinder 3 is pushed upwards by the spiral spring 5. A roller 7 is fixed so that the spring 5 pushes the pile of message forms 1 up till their top edge rests against the roller 7. In this way the top of the pile of message forms is always kept at the same height, the tray rising as the message forms are fed off the tray. Pivoted on each side at 8, two light steel levers 9, one on each side of the tray, carry at their top a steel rod 10. This rod 10 carries three pairs of thrust pawls or prongs 11–11, 12–12, 13–13, the tips of which rest on the pile of message forms; 14 is the platen of the printer, and 15 is

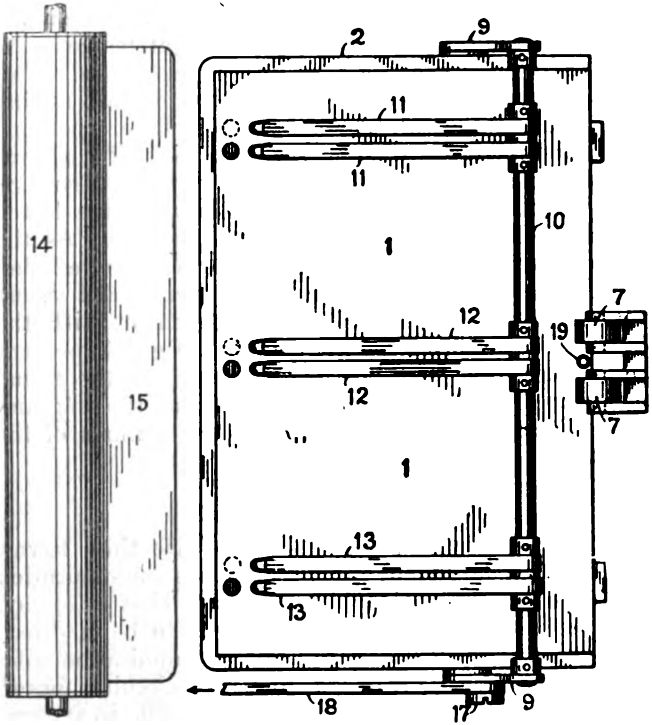

FIG. 324.—Cut page feed: diagrammatic plan view.

the tray of the printer on which the message forms rest as they enter beneath the platen and are fed up round it; 16 are two retaining pawls which prevent the message forms being withdrawn once they have been thrust forward under the platen. A steel strap 18 pivoted at 17 on the lever 9 is attached to suitable mechanism on the page-up of the printer so that at the right moment the strap 18 is pulled in the direction of the arrow. This results in the thrust prongs being pushed forward so that one of each of the three pairs catches in a corresponding hole in the top message form (see Fig. 324). If the three holes are on the left, the three prongs on the left engage. If the three holes are on the right, as shown by the dotted circles, the three prongs on the right engage. As the prongs move forward and engage in the three large holes, the top message form is torn off the pin 19 and thrust over on to the tray 15 and into engagement with the platen 14 of the printer. The pawls 16, Fig. 323, prevent the message form from being withdrawn. In the actual machine a few other details are added, but the diagrammatic illustrations show all the essential features of the invention.

RECEIVING PERFORATOR.

As with the Baudot, it is possible to give three towns, *A*, *B*, and *C*, independent and simultaneous communication with each other on one telegraph wire. That is to say, arrangements can be made for *A* and *C* to be in direct communication while *B* is in direct communication with *A* and with *C*. In addition to series circuits, forked circuits can also be provided, and it is possible to arrange for simultaneous intercommunication between four and even more towns on one wire.

In the Murray multiplex a receiving perforator or reperforator is provided. The adoption of cross-perforated tape has so greatly simplified the receiving perforator that it is now conveniently built in as part of the printer, as shown in Fig. 318 (end-view photo of printer). Under certain circumstances, however, it is convenient to have the reperforator as a separate instrument. It is then essentially a Murray keyboard perforator with the keys omitted. In place of the keys there are five small magnets which do the work of the keys—that is to say, they control selectively five small steel rods, which determine the holes to be punched in the paper tape. These five magnets correspond exactly with the five setting magnets of the multiplex printer (see Fig. 311). Each of these five setting magnets of the receiving perforator is operated by the same impulse from the distributor as the corresponding one of the five setting magnets of the printer. The punching magnet of the receiving perforator is operated by the same impulse as that operating the printing magnet (Fig. 311) of the printer. On the printer there is provided a switch to throw the receiving perforator into or out of action by means of a signal from the distant station. If the sending operator at the distant station *A* has a message which requires to be transmitted at station *B* to, say, station *F*, he transmits a special signal which throws over the switch in the printer at station *B*. This puts the receiving perforator in action. The message is then recorded as perforations in tape by the receiving perforator at the same time as it is being printed in page form by the printer direct from the line signals. At the end of every message the page signal, in addition to feeding up a fresh telegraph form, automatically cuts out the receiving perforator. Consequently only messages requiring retransmission are reperforated, and the sending operator has control over this operation at the distant station. As there is a printed message produced at the same time as the perforated tape, a glance at the printed message will show whether it has been correctly received.

Here it may be of interest to remark that the second or office copy of received messages may be obtained, as in America, by a wet-press copying device. A time-stamp, printing on messages the time, date, number of the circuit, and any other particulars, such as a number identifying the officer receiving and checking the message, increases the speed of operation, and possibly one operator might attend to two printers, save during times of exceptional pressure.

Another plan patented by John Gell provides mechanism for transmitting messages alternately from two transmitters to one printer. Provision has been made for this method of working in the Murray multiplex. This enables three operators to do the work of four, when traffic and other circumstances favour this method of working.

Provision has been made in the Murray multiplex for preparing a number of perforated tapes simultaneously for news distribution, and it may, in future years, play a large part in the distribution of news, even, so its supporters contend, displacing the Wheatstone for this purpose in the British News Division.

PART III.—MURRAY MODIFICATIONS.

The Murray multiplex was developed by Donald Murray with the assistance of the British Post Office to the stage at which it was put on a practical working trial between London and Manchester in 1911. At the beginning of 1912 Donald Murray sold the United States' rights of the Murray multiplex printing telegraph to the Western Union Telegraph Company. The Western Electric Company was called in to assist the Western Union engineers in the work of completing the development of the system, and the manufacture of the apparatus was entrusted to the Western Electric Company. Murray advised the Western Union and the Western Electric engineers about the lines along which development should take place, and these lines have been substantially followed by the Western Union and Western Electric companies, except in regard to the printer that has been adopted by the Western Union. This machine (Fig. 325) is entirely due to the Western Electric Company. It is a type-wheel printer, operated almost exclusively by electro-magnets and relays. It is a column printer and is in appearance not unlike a column printing stockticker, though it is much larger and embodies many ingenious features not to be found in stocktickers.

The printer with the cover removed is shown in Fig.

325. The type wheel and ink rollers are respectively marked 1 and 17. The type wheel is mounted on a vertical spring shaft, which is kept wound up by the motor 10. The selecting discs 13 are notched plates corresponding exactly with the notched bars or "combs"

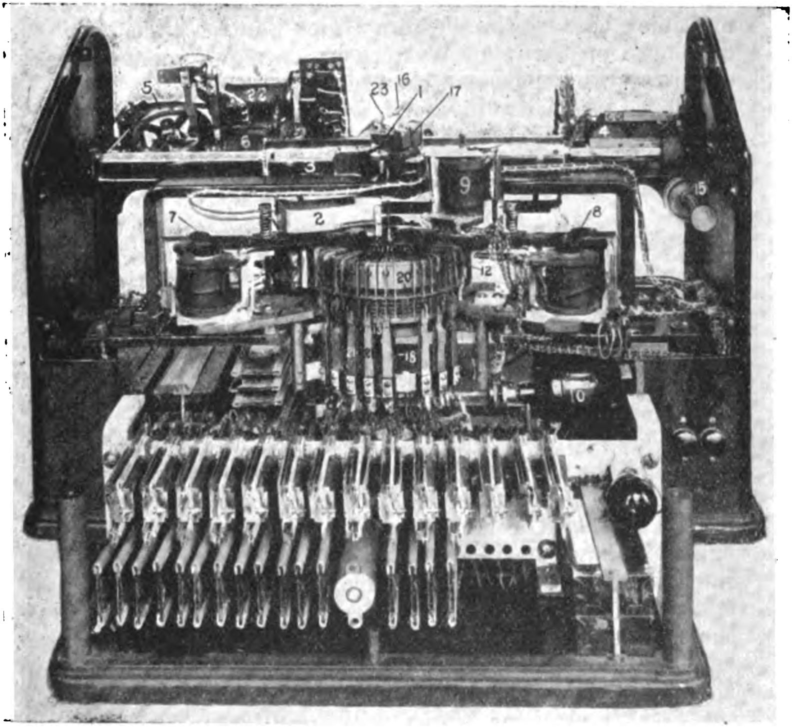

Fig. 325.—Western electric printer.

of the Murray printer. The paper carriage mechanism 5, 6, and 22, serves to feed the carriage 3 along letter by letter. The printing mechanism includes the magnet and hammer for striking the paper against the type wheel. The magnet 4 is used to step up the sheet of paper to a new line.

So far as the rest of the Western Union system is concerned, the Western Union and Western Electric engineers have added a number of ingenious features; but in nearly all essential respects it follows closely on the lines of the Murray multiplex already described. The mechanical design of the Western Union multiplex differs a good deal from its European twin brother, the Murray multiplex, because the Western Union multiplex has been developed primarily for Western Union requirements and American conditions, and the Murray multiplex has been developed specially to work in conjunction with the Baudot multiplex, of which there are about 400 circuits in existence.

WESTERN UNION MULTIPLEX.

The Western Union has adopted the Murray arrangement of the five-unit alphabet, with a few trifling alterations, and the tape as used by the Western Union is identical with that shown in Fig. 307, including the size of the tape and the groups of holes representing letters and numerals. This differs from the Baudot.

The method of synchronism employed by the Western Union is the Baudot clock-hand method of correction of phase, and the phonic wheel motor and vibrator drive to control speed. The Western Union and Western Electric engineers have modified the form of the distributor considerably, but the principle remains the same. On this foundation they have added "correction from the signals themselves," the arrangement being similar to that employed for some years past on the Baudot between Marseilles and Algiers, the chief difference being that the first transmitter works with positive current, the second with negative, the third with positive, and so on, the result being that when all the transmitters are idle positive and negative alternations, each five units long, flow to line, and so keep the two stations running in synchronism.

In the Western Union multiplex, as in the Murray multiplex, transmission is by means of keyboard perforators and tape transmitters. The machines differ in appearance and mechanical design, but their functions are the same, and they include the automatic start and stop for the transmitter as well as back-spacing and invisible correction of errors, as used by Murray in his automatic and multiplex systems; also perforation at the left-hand end of the keyboard perforator and transmission at the right-hand end of the transmitter, so as to have minimum delay between perforation and transmission. In regard to the vibrator, the Western Union has adopted the tuning-fork pattern instead of the single reed. The main advantage is independence of a heavy outside support. The main disadvantage is risk of interference between the two prongs unless they are very carefully tuned. In actual practice there appears to be little to choose between the two forms, at any rate for ordinary multiplex requirements.

The Western Electric printer used by the Western Union has already been explained.

WESTERN ELECTRIC MULTIPLEX.

The "Western Electric Multiplex" is the Western Union multiplex already described and illustrated, including the Western Electric printer, and the only difference is that the Western Electric Company, instead of using the clock-hand method of correction of phase employed by the Western Union, has adopted a modified form of the old Murray automatic plan of securing synchronism by varying the speed of the vibrator by means of buffer springs. It is a speed-varying system of synchronism, as distinguished from the Western Union, Baudot and Murray multiplex methods of synchronism, which depend on uniform speed and clock-hand correction. Instead of the fixed buffer springs employed in the Murray automatic system, the Western Electric Company uses a buffer rod tipped with rubber, which is moved in or out from the vibrator accordingly as speed requires to be increased or decreased.

PART IV.—THE HARRISON PRINTING TELEGRAPH.

This instrument was invented recently by H. H. Harrison for use on circuits where the volume of traffic does not justify multiplex working. It would dispose of the traffic on any simplex, and many duplex, sounder circuits. Indeed, its sphere would be to link up minor towns to the larger centres, where the work would be disposed of by multiplex circuits. It can be used to actuate a Murray reperforator furnishing Murray or Baudot tape, and it can be worked by a Murray or Baudot tape using a Murray or similar tape transmitter. Again, page feeding is justifiable only on very busy circuits, and there are therefore less-busy circuits where the Harrison printer could replace the more costly and complex Murray page-feeding printer. The chief features of the Harrison machine are its cheapness and simplicity. It is largely composed of telephone

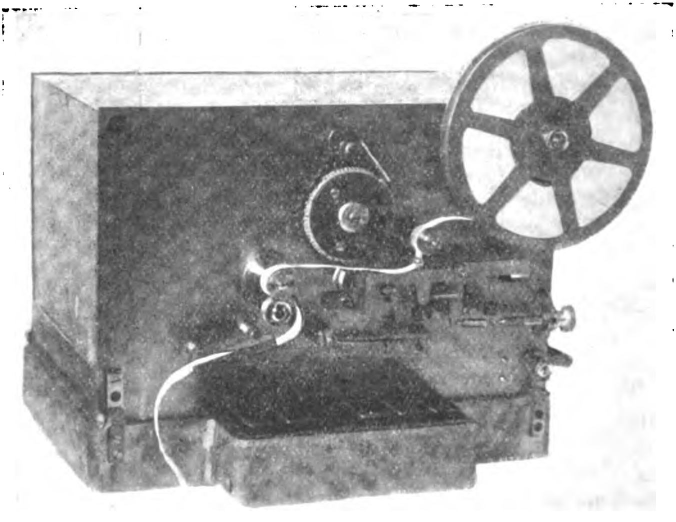

FIG. 826.—Harrison printing telegraph.

parts produced in large quantities, which are therefore produced cheaply.

The instrument is illustrated in Fig. 326. It is provided with a Baudot 5-key keyboard, and has a step by step distributor which is mounted inside the casing. The standard Baudot alphabet is used, but each letter or character is prefixed by a positive starting impulse. Every time a key is depressed a universal bar is actuated which closes contacts giving the starting impulse and the distributors at both ends of the line step through six spaces. The combiner is of the electrical type invented by Baudot, and is similar to that used in Siemen's new automatic printing telegraph. Five relays of the class used for telephone purposes are set at the receiving end, according to whether some of the stepping impulses are positive or negative. The distributor is a trunk hunting switch as used in automatic telephony, and consists of a ratchet wheel and stepping electro-magnet. On the shaft of the ratchet wheel is fixed a wiper which sweeps over a semi-circular bank of contacts in response to the stepping impulses. Two-way working is secured by means of the differential balance.

The apparatus is in course of development, and detailed description is not at present advisable. It may, however, be mentioned that a typewriter keyboard is being constructed to replace the five keys, and thus to enable the apparatus to be worked by operators possessing only typing skill. Its speed of working is about forty-five words per minute.

Owing to the use of the Baudot 5-unit alphabet it will work over very long as well as on short lines, and through ordinary repeaters and on iron as well as copper wires, and for minor circuit work it has the advantages over the telephone of working on a single wire, which may be a long iron wire, and of supplying a "home record" of the message transmitted. It does not need a silence cabinet like the telephone, and there is much less risk of errors in transmitting figures and code messages.

CHAPTER XVI

CENTRAL BATTERY WORKING AND TELEGRAPH SWITCHING SYSTEMS.

CENTRAL BATTERY WORKING.

THE Central Battery System, devised by C. J. Mercer, possesses all the advantages of closed circuit working without the waste of energy involved in the continuously flowing current during idle periods. Apart from leakage current due to the imperfect insulation of the line, current is only used when signals are being made, and this current is usually furnished by the secondary cell installation at the Head Office. The original, and maintenance, costs of the batteries ordinarily required at out-stations are saved, and the apparatus employed is of the simplest possible description.

The arrangement of a three-station circuit is shown in Fig. 327, from which it will be seen that a negative E.M.F. of 80^v is applied to the line through a 1000^{ω} resistance coil, a single current galvanometer with an engraved dial being interpolated in the line chiefly with the object of indicating the insulation of the circuit. The 4 m.f. condensers placed in series with 2000^{ω} polarized sounders are charged by the central battery to a difference of potential of 80^v on a line of perfect insulation. On the depression of the key at, say, station I., the line is earthed and the condenser at each station discharges through its polarized sounder; H.O. via earth to station I., line to H.O. galvanometer and sounder; station I., through the front key contact; and station II. via earth to station I. through the front key contact along the line through station II. sounder to the upper plates of the condenser. In this way momentary currents due to the discharge of the condensers bring down the armatures of the neutrally adjusted sounders, which therefore remain down until the key is released, when the condensers are charged through the polarized sounders. This charging current is in the spacing direction and the armatures rise. The sounders are worked by the current impulses due to the charging and discharging of the condensers through the associated polarized sounders.

At the Head Office the sounder and condenser are connected to the back stop of the key so that the sent signals may not be recorded on the home sounder, thus obviating the noise which would otherwise be made in the instrument room.

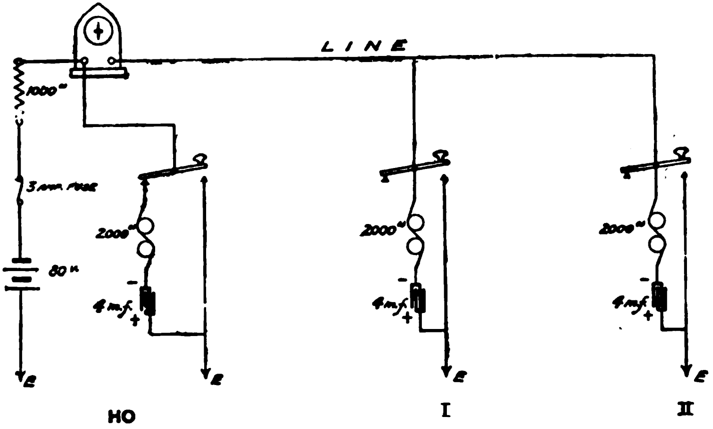

FIG. 327.—C.B. telegraph circuit.

The earthing of the line causes the 80v battery to supply a current not exceeding 80 m.a. during the prevalence of a mark, and upon its termination a current of short duration flows until the condensers are recharged. But on an imperfectly insulated line there is also a certain amount of leakage current, and this current consumption has also to be added to the electrical energy consumption of the system. In comparison with the ordinary closed circuit system described on page 193 this loss is inconsiderable.

The most serious effect of low insulation is to reduce the difference of potential existing across the terminals of the condensers when the keys are at rest. This effect is felt most acutely at the Head Office, and it can readily be shown that the best value to be given to the feeding resistance is equal to the geometric mean of the measured conductor and insulation resistances of the whole line.* As an illustration of the effect of low insulation the voltage applied across the condensers is only 54^v when the total insulation of a line (conductor resistance of 500^ω) is 2000^ω and that the depression of the out station key will reduce this not to zero but to 28^v. With the 3000^ω feed resistance formerly used the corresponding figures would be 32^v and 11^v—an advantage of 5^v multiplied by the capacity used, in favour of the 1000^ω feed.

It may be added that recent experiments have shown that a polarized sounder wound to a resistance of 2000^ω has an advantage of nearly 100% over the 4500^ω sounders at present in use, and therefore in all new installations 2000^ω sounders will be employed.

In the original arrangement a 3000^ω *inductive* resistance was used, but the E.M.F. of self-induction raised the difference of potential across the condensers to about 200^v on breaking the circuit by raising a key. This charge in the condenser had then to fall to its normal value, but to do so a marking current flows through the sounder and the armature is left in the marking position at the end of a signal, and the first signal of the next letter is lost.

*** Central Battery Omnibus Telegraph Circuits, by H. H. Harrison in *Electrical Engineering* of March 17, 1910—**

Let $x =$ feed resistance, $R =$ insulation resistance, and $r =$ conductor resistance. The P.D. at the Head Office, with keys at rest, $V_1 = \frac{R}{x+R}$

The P.D. at the Head Office, with out-station key down, $V_2 = \frac{r}{x+r}$

$$V_1 - V_2 = \frac{R}{x+R} - \frac{r}{x+r} = \frac{Rx - rx}{x^2 + Rx + rx + Rr}$$

which is a maximum when $Rr = x^2$, *i. e.* when $x = \sqrt{Rr}$

See also "The Theory of Central Battery Telegraphs," by R. Bradfield, *Proceedings of I.P.O.E.E.*, Part 36. Also, *P.O.E.E. Journal*, July 1912.

HEAD OFFICE SPECIAL SET.

A special set for use with lines of low insulation is shown in Fig. 328. The Head Office by depressing his key changes the voltage from 80 negative to 80 positive and thus the effect produced upon the out-station sounders is twice as great as would be caused by the earthing of the line on an ordinary set. The standard relay, which is set neutral, is far more sensitive than a polarized sounder, and consequently a much greater working margin is obtained than is possible with the arrangements shown in Fig. 327.

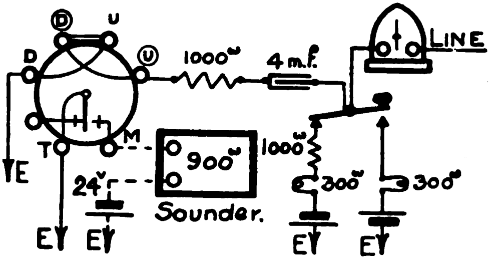

Fig. 328.—Special C.B. set for Head Office

An earlier plan consisted in the use of a $500^{\omega} + 500^{\omega}$ relaying sounder, having an electromagnet placed on its side, so that the mechanically balanced armature moves horizontally instead of vertically.

The relaying sounder was joined in series with an 8 mf. to the centre of the key, and had a 900^{ω} sounder and 24^{v} battery connected to the local contacts.

CENTRAL BATTERY DUPLEX.

The first central battery duplex, described in the earlier editions of this work, was invented by T. F. Purves as an adjunct to his metropolitan switching system. Since then many arrangements have been devised, but it is necessary only to consider those now in general use.

THE HAY DUPLEX.

The arrangement devised by C. E. Hay* (Fig. 329) is a combination of the differential and bridge methods of duplex working. The 80^{v} battery is connected to the junction of two 1000^{ω} resistance coils which form the ratio arms of a bridge duplex, a standard relay and galvanometer being connected across them. The compensation circuit is represented by a 1250^{ω} coil and the resistance of the line is brought up to 350^{ω} by adding a resistance coil of suitable value. At the outstation a $500^{\omega} + 500^{\omega}$ polarized sounder is joined in series with a 500^{ω} resistance coil to earth, and a single current key is joined up so that on depression it short-circuits one coil of the polarized sounder and the 500^{ω} resistance coil, thus reducing the resistance

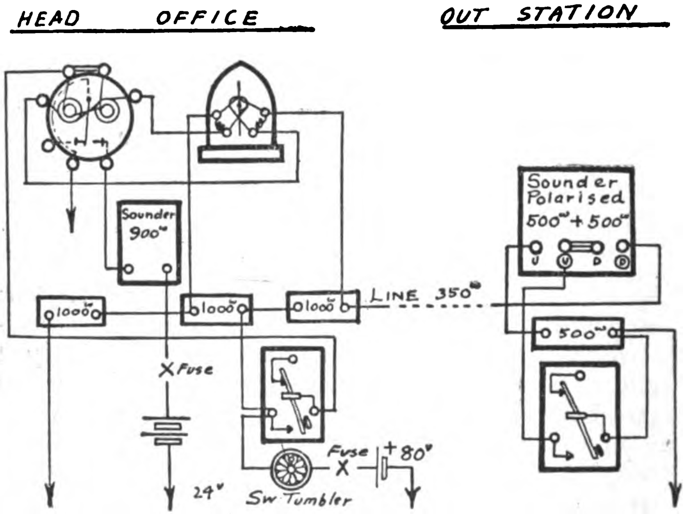

Fig. 329.—Hay C.B. duplex.

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* "The common battery duplex," by C. E. Hay in the *Post Office Electrical Engineers' Journal*, Vol. I. p. 12. "The theory and development of Central Battery Telegraphs," by J. Fraser, a paper read before the Institution of Post Office Electrical Engineers.

of the circuit by 1000^{ω}. The resistance of the line circuit is therefore 1850^{ω} with the key at rest and 850^{ω} when the key is depressed. In the normal condition a spacing current flows through the standard relay connected across the ratio coils, and this current is reversed when the out-station reduces the resistance to 850^{ω} by depressing his key. The polarized sounder at the out-station is joined up so that the current of 25 m.a. normally flowing through its coils almost neutralizes the polarizing effect of the permanent magnet. It may further be pointed out that when the current is increased to 50 m.a. by the depression of the out-station key the sounder is unaffected because this increased current circulates only through one coil of the relay—the magnetic effect on the armature being practically the same as before. Marks are made upon the out-station sounder by depressing the key at the Central Office. This places one coil of the relay and one coil of the galvanometer (143^{ω}) in parallel with each ratio coil, thus reducing the resistance to 125^{ω}. The increase in the current flowing to 40 m.a. with the key at rest or to 80 m.a. with the key depressed, is sufficient to actuate the distant sounder in either position of its key. With both keys depressed the balance of current in the differential relay is upset and more current passes through the *UD* coil and line circuit (850^{ω}) than through the *D*-circle *U*-circle coil and compensation circuit, thus producing a mark on the sounder joined in the local circuit.

The Hay duplex is used chiefly on short metropolitan circuits where the line is almost wholly underground and does not exceed 350^{ω} in resistance.

THE VYLE AND SMART DUPLEX.*

The duplex devised by C. C. Vyle and E. V. Smart is a double current system which may be applied to lines of considerable length, whereas the sphere of the Hay duplex is limited to short lines of high insulation and inappreciable capacity.

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* "A central battery duplex system for long and short lines," by C. C. Vyle and E. V. Smart, *Post Office Electrical Engineers' Journal*, Vol. II. p. 39. "The theory and development of Central Battery Telegraph Systems," by J. Fraser, before the Institution of Post Office Electrical Engineers, March 8, 1909.

At the Head Office (Fig. 330) the connections are those of an ordinary differential duplex, save that a non-polarized *C* relay with 500ω coils and a 6-terminal reversing key are employed. A galvanometer and relay are joined in series at the out-station, and the function of the key is to increase the resistance of the circuit when depressed. In this condition, the rheostat contains sufficient resistance to balance the circuit. The marks at the out-station depend on the direction of the current, and this is determined by the position of the Head Office key. The Head Office marks when the current in the line circuit is reduced by the depression of the out-station key, thus allowing the spring of the non-polarized relay to close the local circuit. When both keys are down, the reduction in the line current marks at the H.O. and its direction is such as to mark at the out-station.

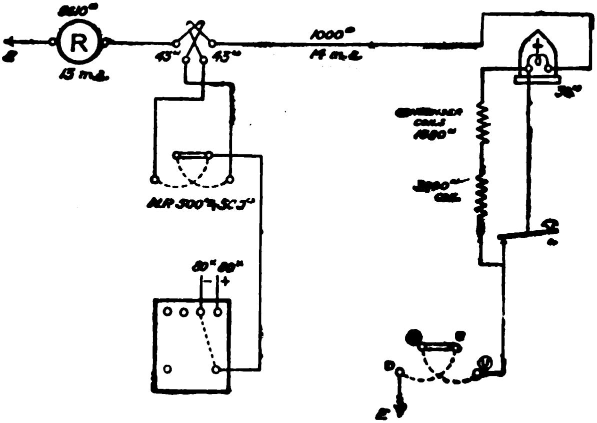

Fig. 330.—Vyle and Smart C.B. duplex. Principle.

The balance and working conditions are obtained as follows :—

(i) With the out-station key at rest the H.P.O.

inserts resistance in the rheostat to produce a deflection of 55° on his galvanometer (a preponderance of 32 m.a.).

(ii) The out-station holds down his key and the Head Office tells him to insert resistance until the needle at the Head Office is vertical, thus indicating the resistance balance.

(iii) The capacity balance is obtained in the usual manner, the out-station key being still depressed.

(iv) The spring of the relay is given sufficient tension to cause the tongue to mark with the out-station key depressed. The correct tension is the mean between that required to make the tongue neutral (*a*) with the distant key up and (*b*) with the distant key down.

It is upon the care with which this last adjustment is made that the success or failure of the working depends.

The rheostat, condenser and retardation coils may be given fixed values on short circuits with little open work and the necessity for operation (iii) avoided.

With a line having a resistance of 100^{ω}, the normal current flowing in the line circuit is—

$$\frac{80}{543 + 1000 + 230} = 45 \text{ m.a.}$$

To obtain a preponderating line current of 32 m.a. the compensation current must be 13 m.a. and the resistance 6153^{ω}, *i. e.* 5610^{ω} is required in the rheostat. When the out-station key is depressed a balance exists and both line and compensation currents are 13 m.a. The tension on the spring should be equal to the pull of 16 m.a. on one coil of the relay. The current at the out-station varies between 13 and 45 m.a., but there no difficulty is experienced.

The full connections are shown in Fig. 331. A 9-terminal 2-position switch is used at the Head Office to change to simplex working whilst a two-way switch and condenser serve a similar purpose at the out-station. When turned to simplex the conditions of Fig. 332 result, and it will be observed that an extension sounder may be provided when it is required that call signals shall also be given in another room away from the set. When this facility is not necessary a 2000ω resistance coil replaces

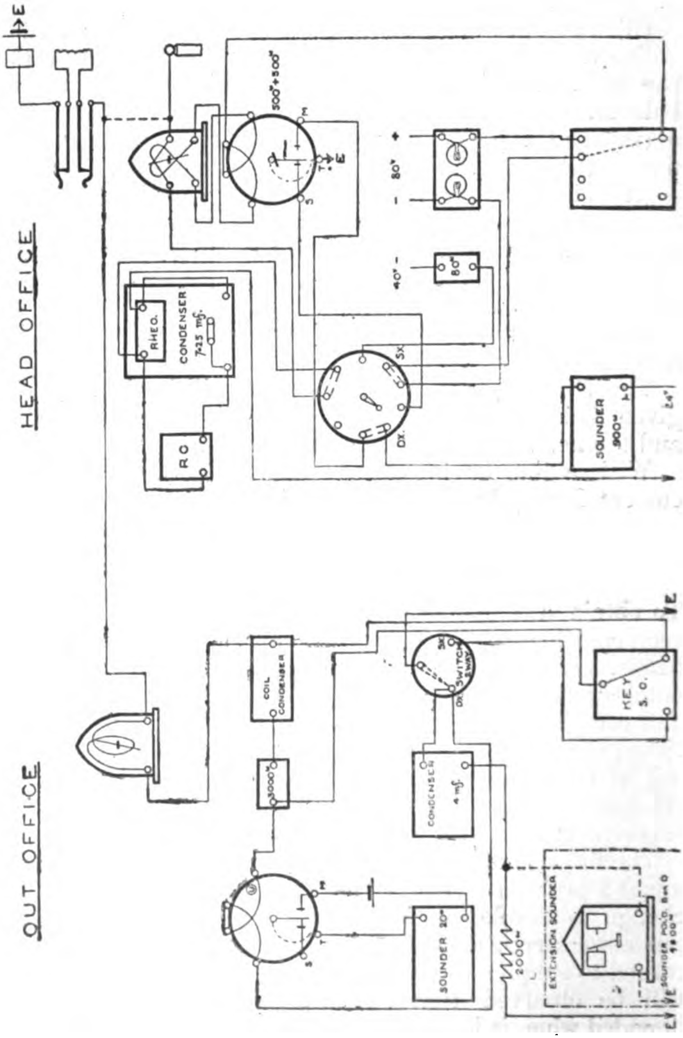

FIG. 331.—Vyle and Smart duplex. Full connections.

the sounder. The relay at the out-station is adjusted to neutrality, and its tongue therefore follows the movements of the Head Office key. The depression of the out-station key earths the line and so completes the circuit of the 40^v battery through the left-hand coil of the non-polarized relay, thus producing a mark. When connected to a concentrator the plug and jack replace the dotted connection shown in the figure.

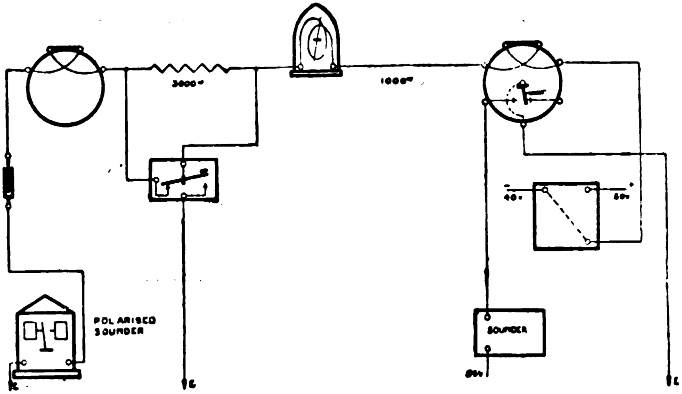

Fig. 332.—Skeleton connections at simplex.

For short and underground circuits the standard relay at the out-station is replaced by a polarized sounder 100ω + 100ω (Fig. 333). The use of this arrangement on circuits over 40 miles in length is unsatisfactory since the volume of the received signals varies appreciably even though the normal current flows through only one coil and the reduced current through both in series.

WHEATSTONE WORKING.

Transmitters and receivers may be added at the out-stations and Wheatstone working adopted by connecting the circuit to a duplex set at the Head Office. During times of emergency this facility is of remarkable value and the distance over which such working can be arranged is very great—in fact, a circuit 364 miles in length has so been worked.*

The Head Office duplex set is shown in skeleton (Fig. 334). It may be a special set joined up as shown in Figs. 205 or 402, but if an up station the batteries, and if a down station the relay or receiver connections, must be reversed. A resistance of 8000^ω is inserted in the rheostat, 4 m.f. in the condenser, and 500^ω in the retardation coil to commence with. The circuit is then balanced with the out-station's key depressed, but if there are two or more stations the mean value is taken and twice this amount is inserted in the rheostat. This produces a definite spacing effect by the compensation circuit. The transmitter is joined up so that the line is earthed when the divided lever rests on the marking side. This upsets the balance at the Head Office, the preponderating marking current in the line circuit being approximately equal to the previous compensation spacing current, and a mark is thereby recorded. A receiver may be added at any station

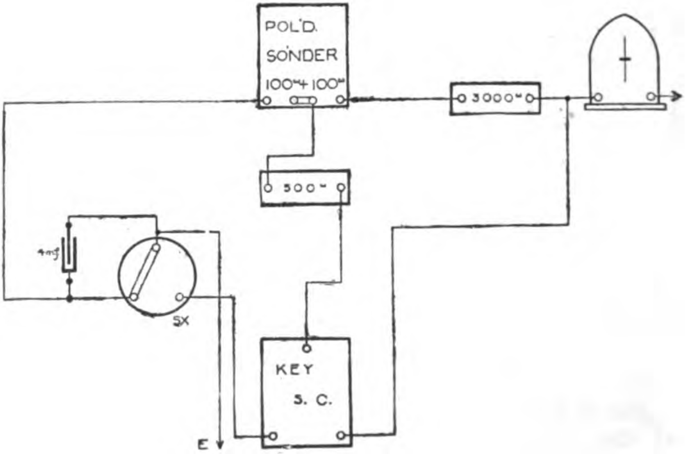

FIG. 333.—Vyle and Smart C.B. duplex for short lines.

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* *Journal of P.O.E.E.*, Vol. III. p. 44.

by joining it in leak with a 2000 resistance coil and 2 m.f. condenser to the centre of the key. The receiver and sounder are worked by the discharge of their condensers direct to earth in the ordinary way when any of the out-stations send either by transmitter or key, but when the Head Office sends by reversing his battery the impulse is greater since the condensers discharge and charge in the reverse direction.

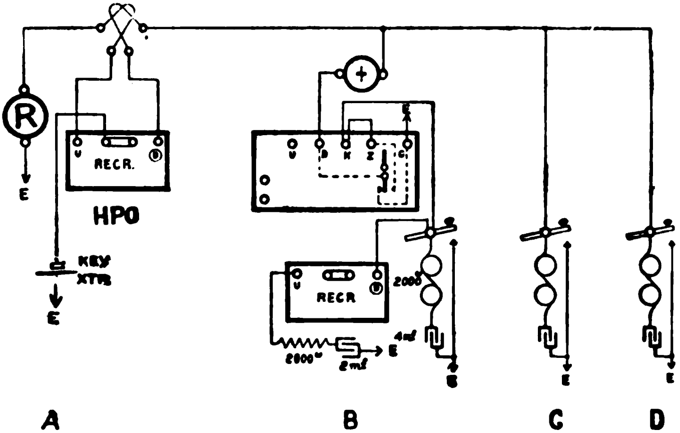

FIG. 334.—Wheatstone added to C.B. circuit.

A transmitter and receiver are shown at *B* (Fig. 334), but transmitters or receivers or both may be added at any or all of the outstations and Wheatstone working adopted between any or all of the stations, *e. g.* by adding a receiver at *D*, *B* may work Wheatstone to *D*.

WHEATSTONE EXTENDED CIRCUITS.*

A central battery omnibus circuit terminating at one Head Office may readily be extended to another office

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* Another interesting arrangement is described by A. Fraser, under the heading, "Fast speed Wheatstone working on underground cable circuits." *P.O.E.E. Journal*, Vol. IV. p 321.

(Fig. 335). The central battery circuit is connected to a duplex set at the Head Office, the battery on the key is reversed, the positive and negative voltages required to work the circuit to which it is to be extended are connected to *S* and *M* of the relay and a polarized sounder and condenser are connected to *T*. The left or receiving terminal of the S.C. key is joined through a two-way switch to *T* of the set normally working to the terminal office. Positive and negative voltages are connected to *S* and *M* of this set, and a sounder and condenser are joined to *T*. The Head Office and terminal office balance in the usual manner, but the duplex connected to the central battery line is balanced as described previously (Fig. 334), and a strong spacing bias given to the relay. When the out-station's transmitter or key earths the line, the balance is upset and the tongue of relay (i) reverses the current applied to the split of relay (ii) and a mark is thereby made at the terminal office. When the terminal office depresses his key the tongue of relay (ii) moves over to *M*, thus reversing the current applied to the split of relay (i) and therefore to the central battery stations. It will therefore be recognized that the tongue of relay (i)

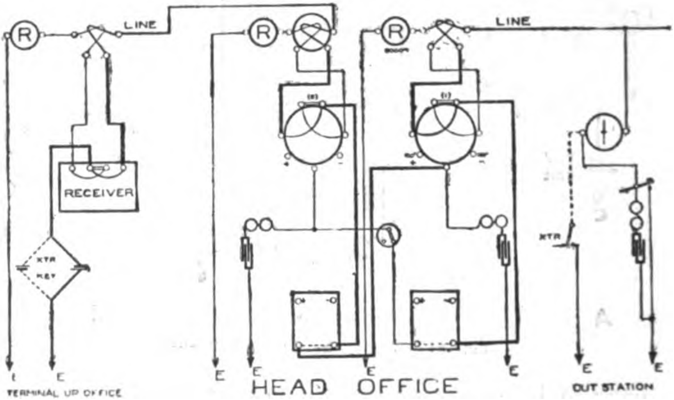

FIG. 335.—C.B. circuit extended to another office.

follows the movements of the transmitter and that the tongue takes the place of the key to relay (ii). Also that the terminal office key controls the movement of the tongue of relay (ii), thereby controlling the sounders (and receivers if used) at the out-stations. By turning the two-way switch to the left the two circuits are entirely divided and may then be worked quite separately.

The circuit shown in skeleton in Fig. 336, which may be used on short or underground lines, provides key simplex or duplex; duplex with Wheatstone from the central and key from the out-station, or Wheatstone simplex from the out-station. At the central station the arrangements are those of an ordinary differential duplex, but a resistance of 500ω is inserted in each battery lead and a 500ω + 500ω non-polarized relay is included in the line circuit. At the out-station the depression of the key introduces a resistance of 4000ω, but it also brings the second coil of the receiver into action, thereby compensating for the reduction in the working current. The normal line current holds the tongue of the N.P. relay away from the contact, but when the out key is depressed and the current reduced the spring pulls over the tongue and a mark is registered on the sounder. The out receiver is operated by the current reversals passing out to line, as also is the polarized sounder which is placed with respect to the resistances in such a way as to obtain an adequate difference of potential.

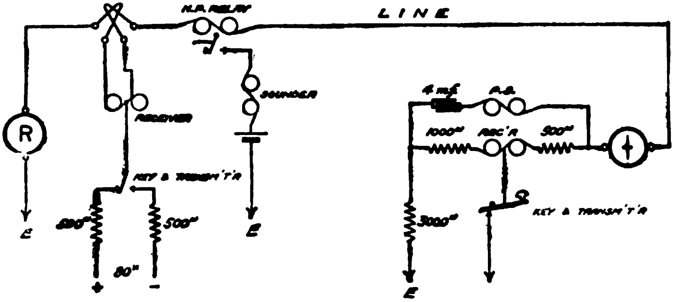

FIG. 336.—Special C.B. circuit giving duplex with Wheatstone working outwards.

THE CONCENTRATOR.

In order to effect economy in Head Office staff, space, and apparatus, all minor circuits are usually joined to a Concentrator, each circuit being connected to an indicator and switch-spring or "jack." A number of working sets of apparatus, generally less than the number of circuits, each terminate in a plug and any working set can thus be connected to any circuit on the switch. Movement of the out station's key actuates the indicator and the switch clerk connects a disengaged set to the line. The indicator is again actuated by the operator who depresses a special clearing key on completion of the message, thus advising the switch clerk when to sever the connection. Messages to be sent to the various offices are dealt with in similar fashion—usually the switch clerk passes the message to a disengaged operator, at the same time making the necessary connection.

Practically all minor circuits are now worked by sounder on the central battery system, and, with the exception of the night concentrator considered later, this is the only type now used.*

AUXILIARY APPARATUS.

The jacks employed are of the five-point type, and consist of four springs and a body or foundation which carries the tube forming the entrance for the plug. The four springs fit into straight nicks made in two ebonite washers, held together to the body by a screw. The circular brass tube fits into the foundation strip of ebonite, to which it is secured by a screw. The general arrangement is indicated in Fig. 337, whilst Fig. 338 indicates the conditions which obtain when a plug is inserted. The body is not used in the system under consideration, and merely serves the mechanical purpose of holding the plug in position.

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* Concentrators to deal with various types of circuits, *e. g.* A.B.C., single and double current sounders, &c., are described in the earlier editions of this work and in *Telegraph Switching Systems*, by T. F. Purves.

The plug is electrically divided into two sections, the ball or tip forming one, and the body the other, part. The plug cover is of ebonite or fibre and insulates the part which is handled by the switch clerk, so as to avoid the possibility of electric shocks. The cord contains two conductors each of which consists of twisted strands of copper tinsel on a silk foundation, the two cores insulated from each other with cotton wrapped outside the strands. The cores are then covered with cotton or linen, and an external braiding of glazed cotton completes the cord. The various improvements in the design of cords have for their object the prevention of faults at the junction of the plug and cord, where the bending is sharpest and most frequent.

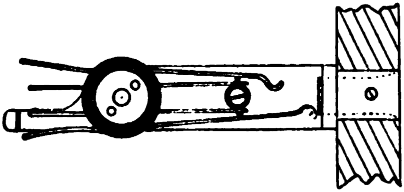

FIG. 337.—5-point jack.

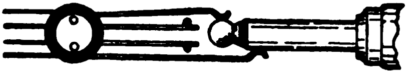

FIG. 338.—Plug inserted in a jack.

A non-polarized indicator relay (Fig. 339) is employed to indicate a call and to close the local circuit of the night bell. It consists of an electromagnet with a soft iron armature held away from its cores by a light spiral spring, the tension on which may be varied by rotating the collet carrying the hook with the aid of the screw at the top of the instrument. The polarized soft iron needle hangs between the cores of the electromagnet, and a current passing through the coils of the instrument deflects the needle to the right or left according to the direction of the current and also attracts the armature, thus closing the local circuit. The coils are connected to the two upper insulated collets and the local circuit to the lower ones, so that the instrument is joined up by the four screws used to fix it.

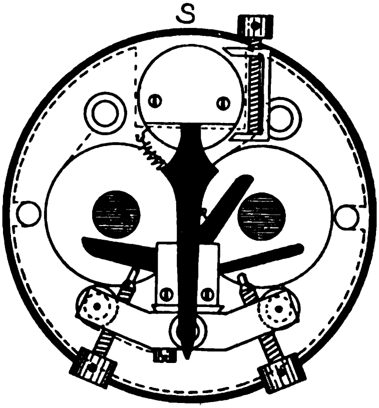

FIG. 339.—Non-polarized indicator relay.

At offices having secondary cell installation where current is readily available the indicator relay is, in the latest form of concentrator, replaced by a line relay and lamp.

The line relay, lamp jack, and lamp are combined in a single unit which is of the Peel-Connor type used largely in telephone exchanges. The lower edge of the soft iron armature rests upon the soft iron extension of the right-hand core of the electromagnet. The armature normally rests upon the lower adjustable screw, and when attracted its proximity to the core is determined by the upper contact screw. Its armature when attracted connects the 40^v battery to the lamp which lights up, thus giving a signal of unexampled conspicuousness. The carbon filament is connected to two brass plates fixed on the sides of the lamp, thus serving to connect it to the two springs of the lamp jack placed beneath the

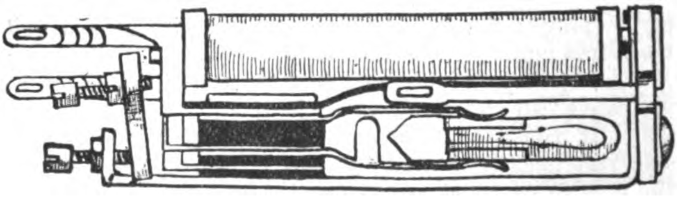

FIG. 340.—Jack, lamp, and relay (type 110 AN).

relay coil. The mounting plate bears a circular hole in front of the lamp in which is fixed a lamp cap consisting of a brass socket with a plano-convex opal lens. Suitable tools have been designed for the removal of the lamp cap and extraction of the lamp when it is necessary to replace either a broken lamp cap or a faulty lamp.

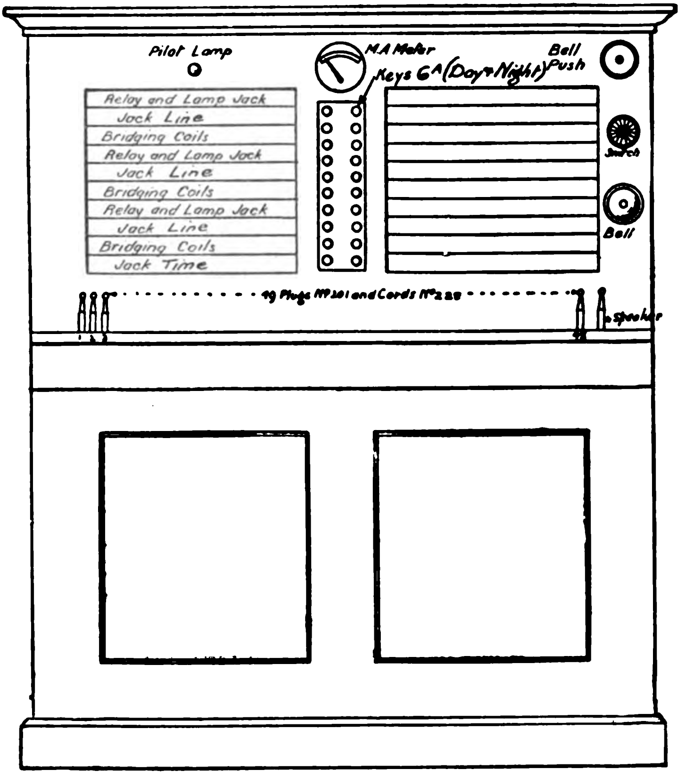

FIG. 341.—Arrangement of a C.B. concentrator for 80 lines.

The general arrangement of an 80-line concentrator is shown in Fig. 341. Each strip contains ten relay and lamp units, beneath which are placed the ten corresponding line jacks and beneath these the bridging coils which are mounted inside the frame. The other details of the apparatus will be apparent after consideration of the circuit arrangements.

The apparatus at the out-stations is as shown in Fig. 327, no changes being required when the circuits are connected to the concentrator. Turning now to Fig. 342, it will be observed that the negative 40^v battery lead, taken from a fuse in the distribution case (*q.v.*) is applied through the 1^ω pilot relay, contacts of the "time" jack, 100^ω line relay to the long spring of the circuit jack, where it passes through a resistance coil to the short spring connected to line. When the out-station signals by depressing his key, and thus earthing the line, the circuit of the line relay is completed and the lamp glows. The resistance (a bridging coil) interpolated between the inner springs of the switch spring is of such a value as to raise the resistance of the line circuit to roughly 1000^ω* and so to reduce the value of the current which flows when the out-station calls. The 1^ω pilot relay, interpolated in the 40^v lamp lead, is energized when any lamp lights, and its local contacts remain closed so long as there is a single lamp on the switch glowing. The pilot lamp associated with this relay is placed in a conspicuous position on the switch, *vide* Fig. 341. Its function is to facilitate supervision since attention can readily be focussed upon it. If the pilot lamp glows continuously it indicates at once that calling and clearing signals are not being attended to promptly.

The calling lamp having been lighted by the depression of the out-station's key, the switch clerk takes the plug connected to a disengaged working set and plugs in on the associated jack. The line is thereby connected via the short spring of the jack and the ball of the plug to a working set joined up, which is, however, joined up so that it will work either to a CB circuit or to any double current circuit which may be connected on the concentrator. The 80^v negative lead (Fig. 342) is connected through 1000^ω feed resistance to the back stop of a single current key, thus providing the normal conditions of Fig. 327, but instead of the polarized sounder a 4 mf. condenser, 1000^ω resistance coil and standard

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* For lines under 100^ω, its resistance is 1000^ω; 100^ω to 350^ω, *r* is 750^ω; 350^ω to 600^ω, *r* is 500^ω; 600^ω to 850^ω, *r* is 250^ω; over 850^ω the inner springs are short-circuited.

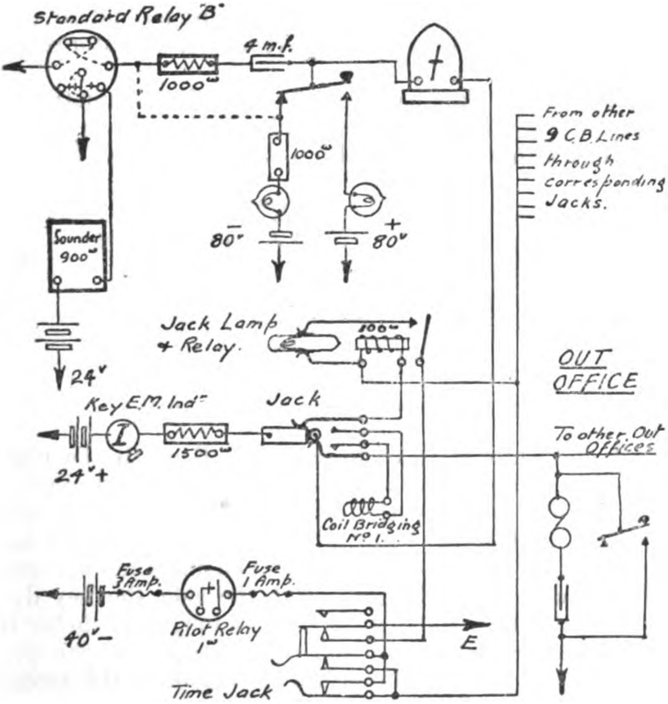

FIG. 342.—Arrangement of C.B. concentrator.

relay with a local sounder circuit are employed for reception. These details are, however, described later.

On completion of the message the operator depresses the button of the indicator Key I which pushes over the armature to the earth-connected contact screw. The circuit of the negative 40^v battery is thus completed; the path is from the positive pole to earth, through the closed contacts of the indicator key, through the coils of the indicator key, 1500ω resistance coil, sleeve of plug, long spring, line relay, through the time switch back to the negative pole of the battery. This current (i) holds the armature of the indicator key to the cores, and (ii) lights the line lamp and pilot relay. The switch clerk then removes the plug, thus breaking the circuit and so permitting the armatures of the line relay and indicator relays to fall back.

The indicator key has been depicted diagrammatically, actually it consists of a relay similar to that shown in Fig. 110, but with a disc divided into twelve parts alternately black and white attached to its axle. Beneath the glass top of the case is placed a blackened disc with six spaces cut so that normally the black sectors of the key disc normally lie beneath them. When the tongue, which has a wide space between the normal and marking contacts, is pushed over by the button at the side, the key disc rotates and the white parts show through the holes in the upper disc. When the operator pushes over the key, the indicator displays the white sectors until the switch clerk clears the circuit.

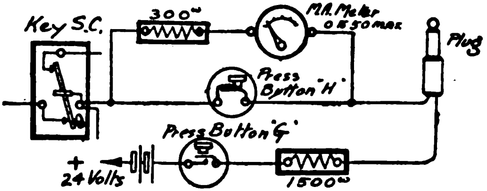

Fig. 343.—Testing apparatus added to speaker set.

Time is signalled by connecting working sets to the jacks marked "Time," one time jack being provided for every ten circuits. The depression of the Head Office key earths the short spring of the "time" jack and the condensers of the ten out-station circuits discharge through their condensers via the line relays and a mark results.

The speaker set is similar to that shown in Fig. 342, but it is provided with a milli-amperemeter reading from 0 to 50 m.a., fitted on the switch-board, and is brought into circuit by depressing the press button *H* (Fig. 343). The insulation and conductor resistance of any circuit is readily obtained by dividing the voltage applied (80^{v}) by the current observed when the circuit is connected with the out-station key at rest or depressed as required. The resistance is $\frac{80,000}{\text{current in m.a.}} - 1600$. The press button *G* which takes the place of the indicator key is used for testing the operation of the line relay.

PARTIAL CONCENTRATION.

It is convenient at most large offices to concentrate the work at night and on Sunday, and for this purpose a jack and plug (termed a 6A Key) are provided for each circuit to be concentrated. These keys are placed in the centre of the concentrator (*vide* Fig. 341). Normally the line passes the jack (Fig. 344) to the set upon which it is worked during ordinary hours, but when the plug key is pressed inwards the two outer springs are connected and the inner springs disconnected, thus joining

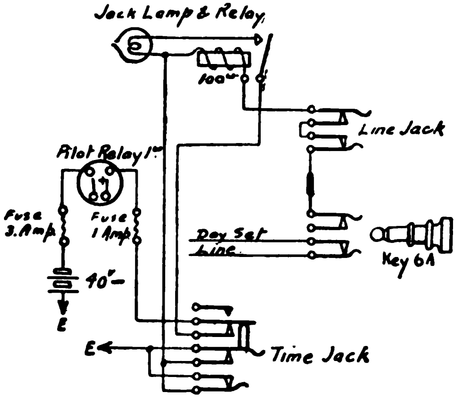

FIG. 344.—Partial concentration.

the line to a line jack and relay on the concentrator. If the circuit thus concentrated is during the day worked with a voltage less than that used on the working sets, viz. 80^v, a suitable resistance coil is inserted between the jack of the plug Key 6A and the line jack on the concentrator.

At offices where a much smaller concentrator only is required the special keys are not provided, and the requirement is met by leaving a plug connected to the working set permanently in the line jack on the concentrator during the day time.

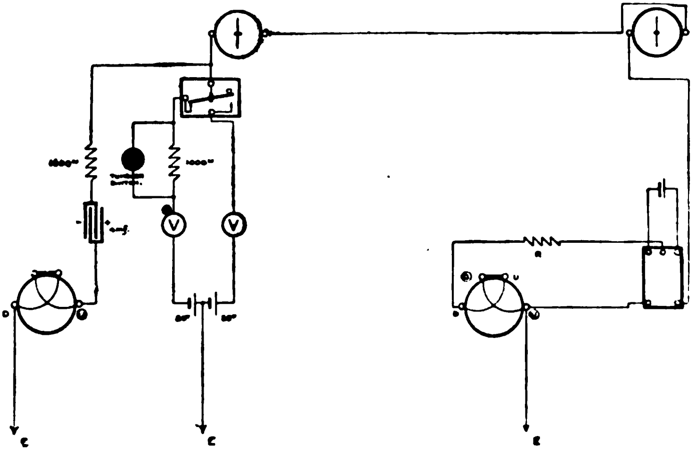

FIG. 345.—Working set connected to a universal D.C. circuit.

WORKING SETS.

The working set shown in skeleton form on the right in Fig. 345 (compare with Fig. 342) consists of a single current key to the contacts of which are connected the 80^v positive and negative leads. In series with the negative lead, connected to the back contact of the key, is a 1000^ω resistance coil which serves as the feed resistance for central battery working, whilst the receiving apparatus, a standard relay set neutral, 4 m.f. condenser, and a 1000^ω resistance coil are teed to the centre of the key. The relay is actuated by condenser impulses on depression of the out-station's key, but instead of the depression of the Head Office key earthing the line, it applies 80^{v} positive, and the out-station's condensers discharge and recharge in the reverse direction, thus strengthening the signal.

In sending to a double current station, the key applies the negative voltage when at rest and the positive when depressed, and marks are produced by the current sent out. When working on very long double current circuits difficulty may be experienced owing to unequal spacing and marking currents due to the presence of the 1000^{ω} feed resistance in the negative lead, and a tumbler switch, by which it may be short-circuited when necessary, is provided. It will be observed that when the Head Office key is at rest the 4 m.f. condenser is charged to 80^{v}, and that when the distant switch is turned and the distant battery connected to line, this charge, assuming equal voltages are employed, is unaltered. But when the *D C* key is depressed and the positive voltage connected to line the condenser discharges, more or less completely, through the relay and reversed battery, and thus the tongue goes over to *M* and there remains until the *DC* key is raised and the condenser recharged through the relay. If the resistance of the line and distant battery are equal to the lamp resistance in the negative lead, viz. 300^{ω}, the condenser is completely discharged when the depression of the distant *D C* key applies 80^{v} positive to line—with a 900^{ω} line, 80^{v} positive would reduce the voltage across the lamp resistance and therefore across the condenser to 40^{v}, and this is at least four times the voltage necessary to operate the relay. So, with a line of higher resistance the voltage acting on the condenser is reduced proportionally. With a 900^{ω} line and a distant voltage of 40^{v}, the difference of potential with the key at rest and depressed across the condenser is 80^{v} and 50^{v} respectively, *i.e.* the discharge is proportional to 30^{v}. On very long circuits when the insulation is abnormally low, the reception of signals by this method of working fails. By turning the two-way switch to "closed" the negative voltage is disconnected from the back stop of the key and the relay joined to the line for the direct reception of the distant signals on the relay (Fig. 346).

The standard method of joining up the *DC* out-stations consists in arranging that positive shall be connected to line to mark and that marks shall be received by the concentrator sets sending positive to line. This involves the reversal of the relay connections and the connection of the galvanometer to line as shown on the right in Fig. 345. Since the standard voltage on the Head Office sets is 80ᵛ it is necessary to add a resistance coil *R* on most circuits to reduce the current to 15 m.a. This coil is placed in series with the out-station's relay instead of in the line, in order to avoid the necessity to increase the out-station's power.

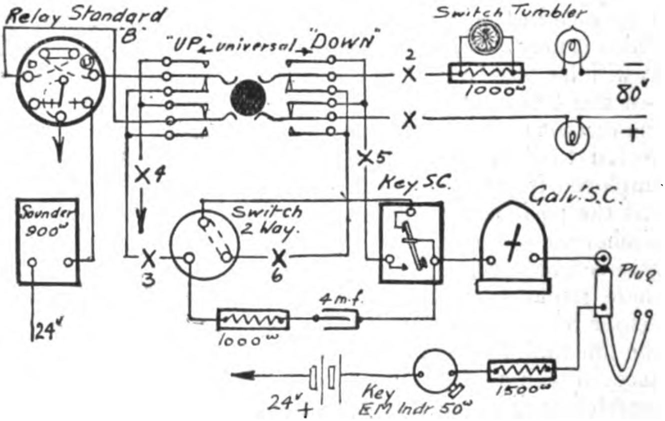

FIG. 346.—Set for working up, down, or universal D.C.

Since some of the circuits connected may have intermediate offices, and therefore ordinary "up" and "down" connections, a key (Fig. 346) is added to the working set which reverses either the battery or the relay as may be required. This key has three positions, the normal, with the springs making contact as shown, for working to offices having the standard or "universal" connections, the left-hand pair of long springs forced outwards reversing the relay, and the right-hand pair of long springs forced outwards reversing the battery leads to the front and back contacts of the key. The connections differ only from those of Figs. 342 and 343 in that the right springs of the key are interpolated between 1, 2 and 5, 6, and the left between 3 and 4.

It should be added that quadruplex circuits when the switch is turned to simplex are identical with ordinary *D C* sets and may be concentrated in the same way.

LONDON METROPOLITAN SWITCHING SYSTEM.

This system, designed by T. F. Purves, is in use in London and enables local offices to be placed in direct communication with each other. Every purely local message is signalled by the office at which it originates to the office from which it is to be delivered, so avoiding the delay involved in re-transmission at the Central Telegraph Office. The time occupied in circulating a received local message to the particular circuit over which it has to be re-signalled and in re-transmission is saved, but against this there is to be set the time taken to establish direct communication, but with the liberal provision of circuits this is not usually very appreciable. Busy offices are given one or more Hay duplex direct circuits for the transmission of foreign and provincial messages, and some 200 working sets connected to the switch are provided at the Central Telegraph Office for the transmission of these messages to and from those offices having only connections to the switch.

The switch provides accommodation for 1150 circuits, viz. 300 switch wires to offices which only collect messages, 650 to offices collecting and delivering, and the 200 working sets. Of these, the 300 collecting offices need only facilities for connection to, and in exceptional circumstances only connection from, the remaining 850 circuits.

Each office is designated by a number, and suitable street lists, showing the offices to which messages for every address within the metropolitan area should be sent, are provided at each office.

MULTIPLE SWITCH.

Thirty-six switch clerks are employed to perform the work of connecting the various circuits together in accordance with the calls received. Each clerk is given a certain number of these circuits, and is responsible for answering and attending to every call *from* them. The group of circuits allotted to any operator is known as the "Home" section of that particular board.

Since any one of these circuits may require to be connected to any other of the 850 circuits, each of them must be within reach of every switch clerk. This condition is readily satisfied by the adoption of the principle of the telephone multiple switch-board. Allowing 2′ 6″ as the sitting accommodation for each switch clerk, and 7′ 6″ as the total space occupied by a switch section at which three operators are seated, it will be recognized that the central operator would readily be able to reach to the furthest extent of the switch-board both to the right and to the left. If, therefore, the whole of the 850 circuits are placed upon a section, every circuit will be within the reach of the centre switch clerk, whilst the outside switch clerks will respectively be able to reach the first and last thirds of the adjacent boards, which are of precisely similar construction. At the beginning of the boards the last third is repeated for the use of the first switch clerk, whilst at the end the first third is placed immediately upon the right of the last complete board. In this way every one of the 850 offices is placed within the reach of each switch clerk.

NEED FOR THE ENGAGED TEST.

Since, however, there are ten complete boards the 850 circuits will have to appear upon each of the boards, it is essential to provide an indication as to whether the circuits are engaged or free. For instance, circuit 562 might be connected by switch clerk No. 1 to one of the "Home" circuits upon that board, and at the same time might be required by switch clerk No. 20 for connection to one of the "Home" circuits which terminate upon that board. In order to avoid this difficulty a small indicator is placed below each switch spring, and these indicators are simultaneously actuated upon all the multiple sections immediately the circuit to which they refer is connected by any of the switch clerks.

METHOD OF OPERATING.

Before entering upon the description of the electrical arrangements required for the working of the intercommunication system it is essential that the method of operating should be clearly apprehended. Each office connected to the switch is represented by a lamp for indicating, and by a jack for answering a call. At the out-station an indicator key (page 540) is provided, which is depressed when attention is required. This key causes the calling lamp at the home position of the switch to light, and so advises the switch clerk that attention is required. The connections are made by means of pairs of pegs and cords in connection with each of which is a speaking key and a clearing lamp, the former for bringing into circuit the switch operator's sounder and Morse key required for receiving and answering calls and the latter for indicating the conclusion of the transaction.

When a calling lamp glows the switch clerk takes up a plug and inserts it in the jack placed directly over the lamp. This operation darkens the lamp and also releases the indicator key at the out-station, thus indicating that the attention of the switch clerk is obtained. The switch clerk by moving the speaking key in connection with the pair of cords to the speaking position brings her sounder and key into circuit. Immediately the out-station observes that the indicator key is released the number of the office required is signalled continuously in abbreviated figures. The switch clerk, in order to avoid error, listens to at least two repetitions of the number and then takes the second plug of the pair and if the required number is not engaged inserts the plug in the multiple jack connected to the required number, and then cuts out her apparatus by restoring the speaking key to normal. The two offices being then in communication the message is signalled direct.

The engaged indicator placed below each jack on the multiple shows whether the circuit called for is engaged or free. In the former case the "*M Q*" signal is given to the calling office, and a second request is made later on; after a call has been made three times, special steps are taken by the switch clerk to obtain the connection as quickly as possible.

Upon completion of the message the indicator keys at both out-stations are pressed, and this lights a lamp attached to the pair of cords with which the connection has been made. This serves as an instruction to the switch clerk to sever the connection, which is done as speedily as possible. The indicator keys are thereby released at both offices, showing that a new call may now be made by either. The conditions are then exactly as they were before the connection was made, *i.e.* the calling lamps and relays are again joined up.

In order to save work and time on the part of the switch operator all connections required for the working sets at the Central Telegraph Office itself are made by means of the Morse key instead of by the indicator key. The call "*T S*" causes the calling lamp to flicker instead of giving a continuous glow. The switch clerk upon seeing a flickering glow merely connects the circuit to a working set without speaking.

ELECTRICAL DETAILS.

The plugs, cords, and jacks are somewhat similar to those described in the case of the concentrator, but of a simpler and smaller type.

The translating relays are of the type shown in Fig. 110.

The skeleton connections of a circuit under normal conditions are depicted in Fig. 347. Normally a permanent spacing current of 6 m.a. from the 36-volt battery flows through the line relay and polarized sounder. This current has no effect upon the comparatively unsensitive line relay. If the indicator key is now depressed the resistance of the circuit is reduced by about 5250^{ω}, which increases the value of the current to 65 m.a., so actuating the line relay and also holding over the armature of the indicator key.

The continuous closure of the local circuit of the line relay produces a steady glow on the calling lamp, thus signifying that the connection is required to another office on the switch. If, instead of closing the indicator key, the call "*T S*" had been given on the Morse key, the current would have been increased only to 28 m.a., but as this is sufficient to work the line relay a flickering glow would result, thus advising the switch clerk to connect the calling office to a working set.

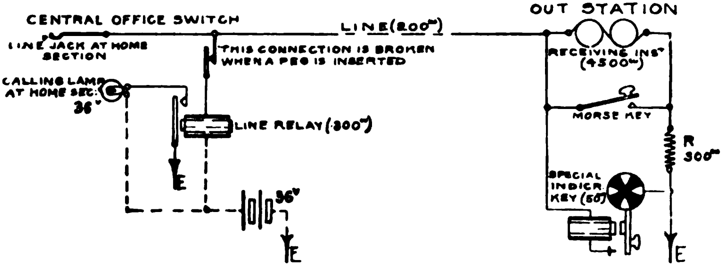

FIG 347.—Skeleton connections of a circuit under normal conditions.

TWO CIRCUITS CONNECTED TOGETHER.

Immediately the switch clerk plugs into one of the jacks on the calling line, the calling apparatus in connection with this line is cut out of circuit, the engaged indicator is actuated upon each of the multiple switch-sections, and by a momentary disconnection of the battery, the out-station's indicator key is released. The speaking key is turned to the "speaking" position and the call is thus received upon the switch clerk's sounder. If the called office is disengaged (shown by the engaged indicator), the second plug of the pair is thrust into the jack of that office upon the multiple. The speaking key is then returned to the normal position, and the conditions depicted in Fig. 348 result. A spacing current flows over both lines from the 36-volt battery via the following paths :—from the positive pole of the 36-volt battery to earth, through 800^{ω} resistance coil at station I., through the polarized sounder, along the line, through the contacts of relay I., through relay II. through the clearing relay to the negative pole of the battery. The path to station II. is similar, save that the current passes through the contacts of relay II. and through relay I. There is therefore a spacing current of about 6 m.a. upon each line, but this is not sufficient to actuate either the translating or clearing relays. If now station I. works his key the resistance of the circuit is reduced by 4500^{ω} when the key is depressed, since the polarized sounder is then short-circuited. This increases the current

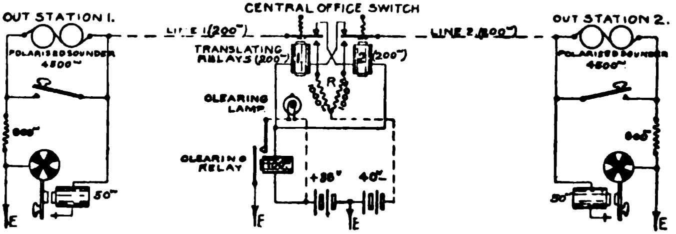

Fig. 348.—Skeleton connections of circuit when two offices are connected together at the switch.

through relay II. to 27 m.a., which causes the armature to descend. This connects the positive pole of the 40 volt battery through 800^{ω} and the lever of relay II. to line 2, so reversing the direction of the current received at station II. It will therefore be seen that when the key at station I. is worked translating relay 2 is actuated in accordance with the signals sent from the key, and that this sends out double current signals to station II. The working may therefore be described as single current *to* the switch from the sending station and double current *from* the switch to the receiving station. When station II. depresses his key relay I. is actuated and double currents are sent to station I. Since a current of about 50 m.a. is needed to work the clearing relay, it will be seen that it also is unaffected by any of these currents.

CLEARING SIGNAL.

When the message has been completed both offices depress their indicator keys, so actuating the clearing relay and lighting the lamp. The action is slightly different at the switch and depends upon which of the two stations first depresses his indicator key. If station II. is first, then the clearing relay is actuated through the coils of relay I. contacts of relay II. and through the depressed indicator key to earth and back to the battery. The value of the current is 66 m.a., and the circuit of the indicator key is continuously maintained. The descent of the armature of relay I. puts a marking current due to 40 volts on the line I., and when the indicator key is depressed, the current rises from 6 to 38 m.a., which holds over the indicator key. Similarly if station I. first depresses his indicator key, No. 2 translating relay is actuated; this will, however, be obvious. Immediately the clearing signal is observed the plugs are withdrawn, the indicator keys are thereby released and the conditions of Fig. 347 restored.

SPEAKING APPARATUS.

The switch clerk's speaking apparatus consists of a key and a relay and sounder. The key earths both the translating relays when depressed, thus causing both armatures to descend, and so sending out a marking current to both stations, or to only one of them if only one plug is inserted. The speaking relay is joined up in place of the clearing relay, by means of the speaking key on each pair of plugs and cords, and is thus actuated in accordance with and when either of the translating relays is worked by the stations.

COLLECTING OFFICES.

It has previously been pointed out that there are a number of offices which only collect and do not deliver messages. In such cases connections *to* these offices are but seldom required, and therefore it is unnecessary to connect them to the multiple sections of the switchboard. Each of these circuits terminates in a plug furnished with a speaking key and a lamp which does duty both as a calling and as a clearing signal. The depression of the indicator key lights the lamp, and the switch clerk then enters the circuit by means of the speaking key. After ascertaining the number of the office with which connection is required, the plug is lifted from its place and the calling lamp is at once darkened. This is accomplished by a socket contact which is broken when the plug is in its normal position, and which is made when the plug is raised. The plug is then inserted in the jack of the called line, the speaking key is returned to normal and conditions somewhat similar to those of Fig. 348 obtain. The difference lies in the fact that the lamp and its relay serve the double purpose of calling and clearing. When the indicator keys are depressed this lamp is lighted and the connection is severed. The advantage of this arrangement is that the operation of inserting the first plug of a pair in the home jack is saved. It may therefore be said that one-half of the operation is already done when single cord working is adopted.

ENGAGED TEST.

The principle of the engaged test is shown in Fig. 349. When a plug is inserted in any jack the body of the plug connects the body of the jack to its long spring. In this way the doubled-tongued "cut off" relay is actuated, so cutting out the calling apparatus and, at the same time, actuating all the "engaged" indicators. In the event of the failure of this "engaged" device the condition of any circuit can be ascertained by touching the bush of the jack with a plug connected to an earthed lamp. If engaged, the 36 volt battery, being connected to the bush of the jack, therefore causes the earthed lamp to glow when connected by tapping with this special plug provided for the purpose.

INTERMEDIATE OFFICES.

There are certain cases in which two offices share a single switch wire. The intermediate and down stations are connected to the line in leak, and the resistance of each is raised so that the total permanent current sent out to both offices is the same as that sent out upon a one office circuit. In both cases this reduces the received working currents to half the value of that obtained upon a circuit without an intermediate station upon it. It is, however, found that satisfactory working may be obtained with this reduced current, and it only remains to indicate the arrangements by which either station may ascertain whether the other office is working. At the intermediate office a differential galvanometer, with its coils in parallel, is placed in the line circuit, while a 900$^\omega$ single current galvanometer is joined in series with the polarized sounder at the down or terminal station. The current which passes through the translating relay when the key is depressed is precisely the same as in one office circuits, and therefore no special adjustment of the translating relays is required. When the down office is working the current of 28 m.a. which passes along the line deflects the differential galvanometer at the intermediate station, so indicating that the circuit is engaged. The key at the intermediate station disconnects the down station every time it is depressed, and so causes the needle of the 900$^\omega$ galvanometer to oscillate.

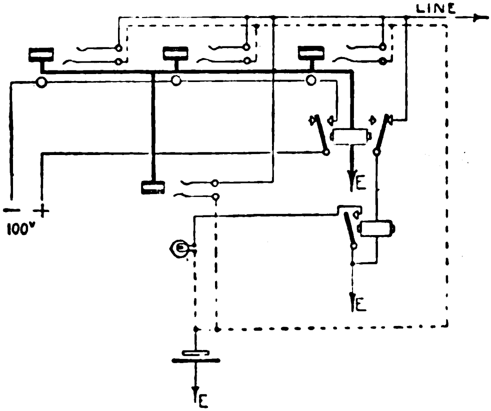

FIG. 349.—Engaged test and connections of jacks upon the multiples and home sections.

The down station's indicator key when depressed produces a large deflection on the differential galvanometer.

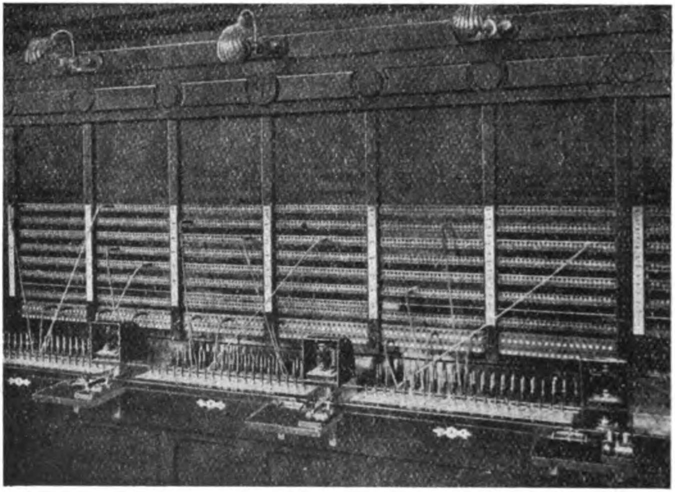

FIG. 350.—Multiple telegraph switchboard.

The intermediate indicator key cuts off practically all current from the down office, which clearly indicates the condition of the circuit to that office.

OTHER DETAILS.

The intercommunication system also meets the following requirements:—

1. Two speaking keys cannot be simultaneously depressed by a switch clerk.

2. Greenwich "Time" is signalled by a bunching arrangement resembling that of the Concentrator, but only one line is taken in the case of offices having two or more lines.

3. Two offices may be placed upon a single switch circuit when necessary by connecting them in parallel and arranging so that the resistance *from* the switch is the same as for one office.

4. A pilot lamp to show that all calls are promptly attended to and to prevent the failure of a calling lamp from causing a stoppage of the circuit without such failure being known. This also provides for the ringing of a bell at night when any station calls.

5. Special arrangements are made for the rapid removal of defectively adjusted translating relays and for their readjustment by means of a testing set.

6. A special device to indicate automatically when any particular pair of circuits is free. This is to ensure that, where an office has been waiting for another for some time, the waiting office shall have the next turn.

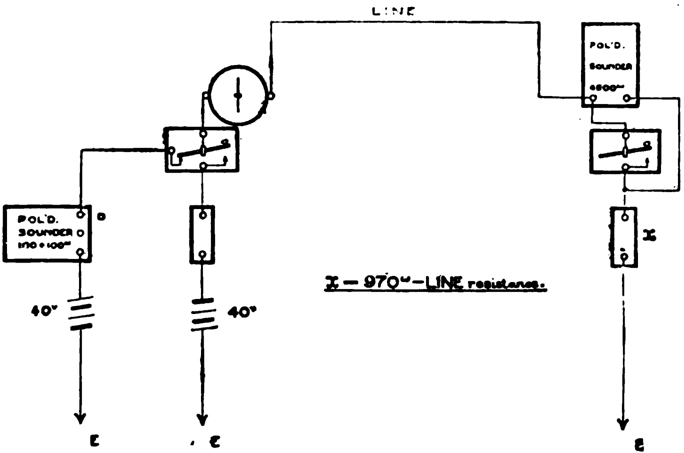

Fig. 351.—Special circuit for working through the switchboard.

Special Set for working through the Switch.

An example of another central battery arrangement is shown in Fig. 351. The $100^{\omega} + 100^{\omega}$ polarized sounder is biassed against the 7 m.a. spacing current sent out but is actuated when the current is increased to 33 m.a. by the depression of the distant key. The Head Office signals by reversing the current from 7 m.a. spacing to 7 m.a.

marking, and this is ample to produce good signals on the 4500^{ω} sounder.

In order to work circuits operated during the daytime from sets in a part of the office which it is required to close at night, special sets joined up as shown on the left of Fig. 351 are provided, and by means of a double pair of cords the requisite connections are made for the circuit to work through the intercommunication switch.

The details of the Metropolitan Switching System would occupy far more space than is available in the present volume, and the reader who requires fuller details is referred to *Telegraph Switching Systems*, by T. F. Purves, who designed the complete system, and to *La batterie centrale en télégraphie*, by the same author, to which sources the writer is indebted for the whole of the information contained in this chapter.

CHAPTER XVII

SECONDARY CELLS.

A SECONDARY cell or accumulator is a reversible primary cell in which chemical energy may be restored to the cell in return for electrical energy. It has previously been shown that when a current is taken from a primary cell the constituents of the cell are re-arranged in such a way that the electrical energy produced is accounted for by the difference between the chemical energy possessed by the cell in its original and in its re-arranged forms. If an electric current is passed through an exhausted cell in opposition to its E.M.F., the chemical compounds re-assume their original form and a current may again be taken from the cell. In this operation electrical energy is transformed into chemical energy. Every primary cell will, to some extent, behave as a secondary cell.

The secondary cell of practice may be defined as a voltaic cell such that, when discharged, the elements combine with the electrolyte to form compounds which remain insoluble, which compounds may be converted to their original condition by the passage of a current in the reverse direction.

The first lead cell, invented by Gaston Planté in 1860, consists of two lead plates coiled spirally, and separated from each other by flannel, the whole arrangement being immersed in dilute sulphuric acid. When the plates are connected to a battery having a sufficiently high E.M.F. to produce a current through the cell, peroxide of lead (PbO_2) is formed on the positive plate whilst the negative remains lead. Upon discharge, both plates are coated with lead sulphate ($PbSO_4$), which upon re-charge is converted to spongy lead at the negative and peroxide at the positive. The E.M.F. of the cell is about 2 volts.

The pole and plate which is connected to the positive pole of the battery, and which, when discharging, is the positive pole of the cell, is termed the positive plate and pole. This convention differs from that used in the case of primary cells where the positive pole is the negative element. This is equally true of secondary cells, but convention and usage have established the nomenclature already mentioned, and it will now be understood that by the positive and negative plates are meant those to which the positive and negative poles of the battery or other sources of E.M.F. are respectively connected for charging purposes. The positive plate is readily recognizable by the brownish tinge which the peroxide of lead gives it during charge, whereas the negative partakes a greyish tinge.

When the elements have become fully charged, *i. e.* the complete peroxidization of the positive and reduction of the negative, the only effect of further charging is to decompose the water of the electrolyte into its constituents, hydrogen and oxygen, the former gas being evolved at the negative, and the latter at the positive, electrode. During discharge the active material in both plates is partially converted into lead sulphate, but these reactions will later be described.

Planté also discovered that by charging and discharging and then charging in the reverse direction the capacity of the cells could be greatly increased. This process was repeated many times before the cell had gained anything like its maximum capacity, and is known as the process of formation. Formation renders the surface of the plate more porous, thereby increasing its active surface. The cell under this treatment continually gains in capacity until finally the plates fall to pieces from lack of mechanical strength. Unfortunately, the more efficient the plates become from an electrical point of view the worse they grow mechanically.

From the chemical standpoint, all secondary cells with lead plates and dilute sulphuric acid are exactly alike, although the details of design and manufacture may differ considerably.

Cells in which lead is used only for one element, and some in which lead is not employed at all, are described in treatises exclusively devoted to secondary cells, but no cell of either of these types is yet in practical use.

Every improvement upon the Planté cell has for its object the reduction of the costly and tedious process of formation, the improvement of the mechanical structure, *i. e.* the prevention of the destruction of the cell by the ever-increasing porosity of the lead, increase of the active surface, and reduction of the weight of the cell.

In 1880 Faure constructed and obtained the patent rights for a cell in which the active material was applied to the plates in the form of a paste instead of being produced by formation. Priority of invention is usually awarded to Metzger in 1878, but there is no doubt that Faure's results were independently obtained. Faure pasted both positive and negative plates with a paste formed by mixing red lead (Pb_3O_4) and sulphuric acid. The mixture formed lead sulphate ($PbSO_4$), thus:—

$$Pb_3O_4 + 2H_2SO_4 = 2PbSO_4 + PbO_2 + 2H_2O$$

Upon the positive plate the mixture was completely converted into peroxide of lead by the liberated oxygen, whereas upon the negative plate it was reduced to spongy lead by the liberated hydrogen combining with the oxygen of the lead peroxide, and the acid radicle (SO_4). This paste of Faure's does not adhere very well to the plates, and hence many of the later improvements are directed towards the remedying of this defect.

The Planté and the Faure cells represent two great prototypes. Modern practice, however, consists very largely in the use of Planté positives and Faure negatives, the Planté negative being quite extinct. Practically all manufacturers use pasted negatives whether they are to work with pasted or Planté positives.

CHEMISTRY OF SECONDARY CELLS.

The chemistry of secondary cells is not known with any degree of certainty at the present time, and this notwithstanding the fact that many eminent chemists have devoted much study to it. The substances used as active materials are, in the first place, mixtures, and will not dissolve in any solvent without decomposition taking place, thus rendering a quantitative determination of the active constituents very difficult, if not impossible. Many theories, more or less complex, have been evolved, but none of them entirely explain the changes noticed.

The chemical action of all secondary cells of the lead-sulphuric acid type is the same, for their only differences are in the form of the plates or grids and the method of preparing the active material. In cells of the Faure type the negative plate is pasted with a mixture of litharge (lead monoxide) and sulphuric acid, since this requires less energy to reduce than a higher oxide such as minium (Pb_3O_4), which is generally used for the positive active material. The effect of charging such a cell is to reduce the litharge or sulphate of lead, as the case may be, to spongy lead at the negative and to form lead dioxide at the positive. A charged Planté cell has the lead at the positive oxidized and spongy lead formed at the negative. The formation of the cell consists in producing the maximum quantity of active material (spongy lead and lead dioxide) upon the plates. It will thus be seen that charged cells, whether of the Planté or Faure type. are precisely alike as regards their chemical condition.

The theory which is now most favoured and which most nearly fits the experimental facts is known as the double sulphation theory. It owes its origin to Gladstone and Tribe, two of the earliest workers in the field, and very probably with slight modifications will prove to be true. Before the publication of their researches the electrolyte was held to be water, and the presence of the acid was regarded as merely improving the conductivity of the water. This theory is now universally admitted to be erroneous. The electrolyte is sulphuric acid, and according to the double sulphation theory the action may be represented as under :—

First Stage—

Charged. *Discharged.*

Positive. Negative. Positive. Negative.

$$\underset{\substack{\text{One}\\\text{molecule}\\\text{of lead}\\\text{dioxide}}}{PbO_2} \underset{\text{and}}{+} \underset{\substack{\text{Two}\\\text{molecules}\\\text{of}\\\text{sulphuric acid}}}{2\ H_2SO_4} \underset{\text{and}}{+} \underset{\substack{\text{One}\\\text{atom}\\\text{of}\\\text{lead}}}{Pb} \underset{\text{form}}{=} \underbrace{\underset{\substack{\text{One}\\\text{molecule}\\\text{of}\\\text{monoxide}}}{PbO} \underset{\text{and}}{+} \underset{\substack{\text{One}\\\text{molecule}\\\text{of}\\\text{sulphuric acid}}}{H_2SO_4}} \underset{\text{and}}{+} \underset{\substack{\text{One}\\\text{molecule}\\\text{of}\\\text{water}}}{H_2O} \underset{\text{and}}{+} \underset{\substack{\text{One}\\\text{molecule}\\\text{of lead}\\\text{sulphate}}}{PbSO_4}.$$

The monoxide of lead and sulphuric acid are shown bracketed together since they react and thus form lead sulphate and water. This action is purely chemical as distinguished from electro-chemical, and therefore has no effect upon the E.M.F. of the cell.

Second Stage—

Action at the positive pole:—

$$\underset{\substack{\text{One}\\\text{molecule}\\\text{of lead}\\\text{monoxide}}}{PbO} \underset{\text{and}}{+} \underset{\substack{\text{One}\\\text{molecule}\\\text{of}\\\text{sulphuric acid}}}{H_2SO_4} \underset{\text{form}}{=} \underset{\substack{\text{One}\\\text{molecule}\\\text{of lead}\\\text{sulphate}}}{PbSO_4} \underset{\text{and}}{+} \underset{\substack{\text{One}\\\text{molecule}\\\text{of}\\\text{water}}}{H_2O}$$

The final result of complete discharge is, then, to convert the whole of the active material upon both plates into lead sulphate and also to remove sulphuric acid from the electrolyte. Lead sulphate is, however, a very bad conductor, and therefore the *whole* of the peroxide is not acted upon, thus leaving at the end of the discharge a quantity of peroxide covered over by a coating of sulphate.

Charging changes the lead sulphate to lead dioxide upon the positive and to spongy lead upon the negative, which causes the positive plate to assume a deep chocolate and the negative a light grey colour. When the cells are discharged the colour of the positive will be found to have grown lighter, though still of the same colour. The semi-transparency of the lead sulphate accounts for its not showing itself in the form of a grey colour upon the plates

THE HYDROMETER.

From consideration of the equations given above it will be observed that the percentage of acid in the electrolyte is greatest when the cell is fully charged and is least when it is completely discharged. The specific gravity of the solution is therefore an index to the charge or quantity of energy in the cell. It also serves as a guide to the behaviour and conditions of the cells. The type of hydrometer most frequently employed for testing the gravity is shown in Fig. 352. Its range is from 1·150 to 1·250, the gravity of pure acid being 1·840. The hydrometer is allowed to float in the solution, the gravity of which is equal to the value marked upon the scale at the level of the liquid.

The ordinary hydrometer is read by the marks on the scale at the surface of the electrolyte which, due to surface tension, heaps up around the stem and thus renders very accurate readings impossible. The recently designed Lucsmart device obviates this difficulty by raising the cursor line or reading point above the level of the electrolyte with the aid of a float. The hydrometer proper is of course specially calibrated in conjunction with the float. The arrangement will, however, be quite apparent from a consideration of Fig. 353, and it may here be emphasized that a close study of the readings gives infallible indications as to the behaviour of the cells.*

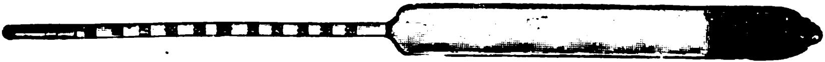

FIG. 352.—Hydrometer.

EXPANSION OF THE ACTIVE MATERIAL ON THE POSITIVES.

Before passing on to descriptions of the various types of secondary cell, it should be stated that with the exception of the cell described on page 566, the number of negative plates exceeds the positives by one in every form of cell described. This is in order that both sides of the positive may be acted upon, and the tendency of each side to bend or "buckle," due to the expansion of the active material, may be made equal. For the same reason the positives are usually thicker and stronger than the negatives, which have but little or no tendency towards buckling.

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* "Secondary Cell Maintenance," by J. G. Lucas, *P.O.E.E. Journal*, Vol. VI. p. 336.

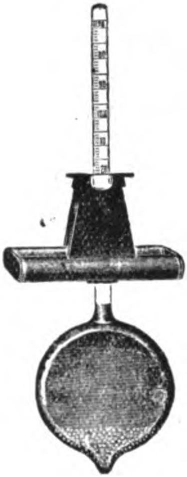

Fig. 853.—"Lucsmart" Hydrometer.

In some types of cell the outside negative plates are in reality half-plates, having a surface of active material only on the inside, and plain lead backs facing the containing box. This is, in most instances, a distinct advantage, since more even working of the outside positive plates is thereby attained, and the tendency to buckling materially reduced.

Chloride Cells.

A third or intermediate class between Planté and Faure is the well-known Chloride accumulator, so largely employed in connection with the Common Battery Telephone system. In this type of cell the active material is neither applied to the plates in the form of a paste, nor is it formed actually on the plate itself, but on spirals of lead tape, contained in the grid itself.

The lead antimony mixture of which the grid of the positive plate is formed is run into moulds under an air pressure of 180 lbs. per square inch, in order to ensure a perfectly homogeneous casting. The 124 circular holes of the "S" type are cast countersunk on both sides of the plate so as to provide for the expansion (during formation) of the active material which they support. This active material consists of a tape of pure lead which is pressed cold at a pressure of 4,000 lbs. per square inch, is gimped with grooves and ridges in a button machine, which cuts off the requisite length and winds it into a rosette. The rosettes are inserted in the holes in the plate, and finally subjected to a heavy pressure, thus driving the buttons home and ensuring perfect contact. The plate is then subjected to a modified Planté formation process, during which the surface of the rosette is peroxidized.

The negative plate is made in two halves, riveted together after the insertion of the active material, which is thus contained in a series of small cages or boxes, and for this reason the type of plate is called the "box" negative. It will be noticed from the illustration that the outside of a plate is covered with a finely perforated sheet of lead which prevents the active material from falling out. The chief advantage of this method of construction is that the capacity of the plate can be maintained practically constant over a long period of years, owing to the arrangement of the active material and its special composition.

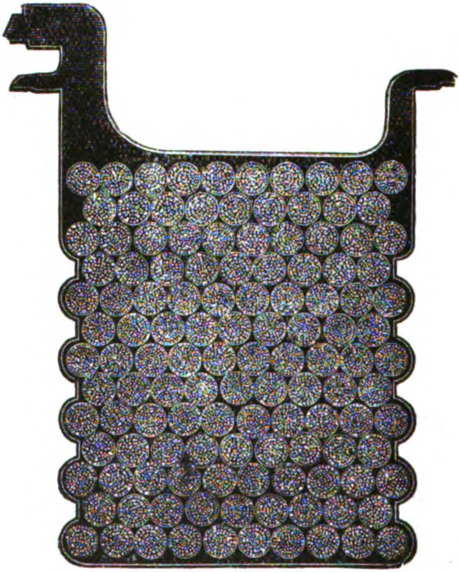

FIG. 354.—Chloride positive plate.

The old type glass rod separators have been abandoned in favour of wood separators, which consist of a thin sheet of wood slightly larger than the plate with which it is employed. The wood forming the separator is subjected to a special treatment before being put into the cell, which entirely removes from it all substances which would otherwise be deleterious to the plates and cause rapid disintegration. It is supported by slotted dowels, each hung on rubber rings resting on the top edges of the plates. This separator forms a continuous diaphragm between plates of opposite polarity, and entirely obviates any possibility of internal contacts. It also possesses the peculiar property of tending to maintain the capacity of the cells in a way which cannot be effected when either glass rods or ebonite forks are employed. By the use of these wood separators the amount of attention required by a battery is considerably reduced, and their employment in no way increases the internal resistance of the cell.

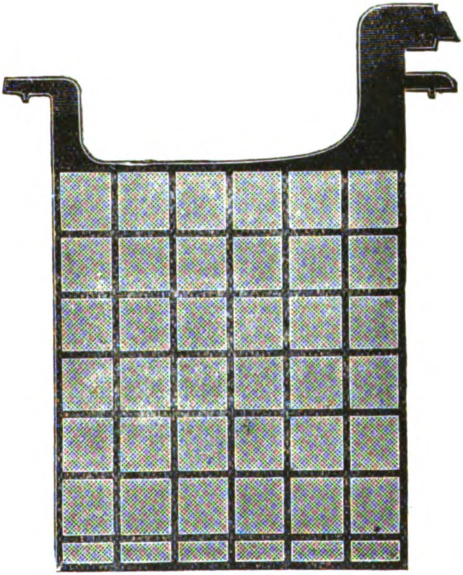

FIG. 855.—Chloride negative plate.

One type of cell for very small capacities for telegraph work is the Chloride "K.G.T." 2-plate type illustrated in Fig. 357, in which each cell contains two plates only, one positive and one negative, instead of one more negative plate than there are positive plates, as is usually the case. The positive plate and the negative plate are burned to a lead connecting strap before being despatched, and are readily installed by bending the lead strap so that it rests on the edges of the two adjacent glass boxes, thus dispensing with bolted connections. The cells are arranged five in each tray, so as to form 10-volt units. Rubber rings are placed round each alternate box to avoid any possibility of surface leakage from cell to cell. For capacities of 10 ampere hours and upwards, the "K.X.G." type illustrated in Fig. 358 is employed. In this type

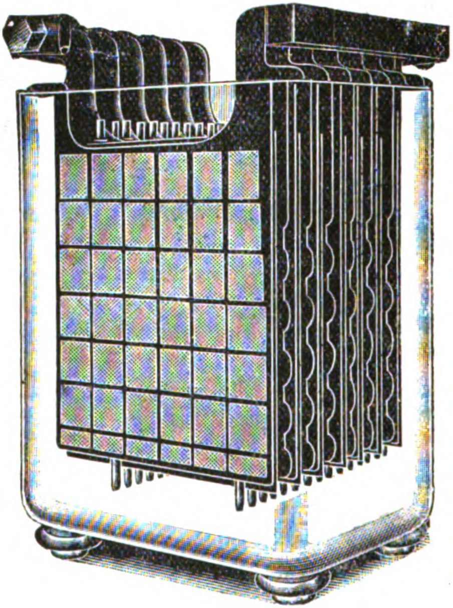

FIG. 356.—Chloride cell.

the plates are suspended from a cross bar, which rests on the edges of the boxes, the number of contacts with the box being thus reduced to a minimum, and whilst there is, moreover, no possibility of siphoning over of the electrolyte, a defect which sometimes occurs when small

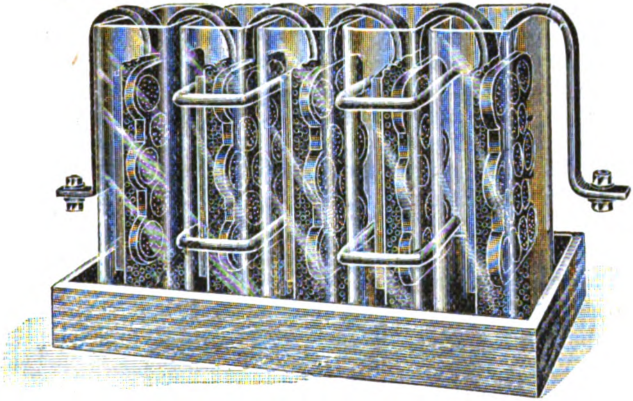

Fig. 357.—Chloride K.G.T, cells,

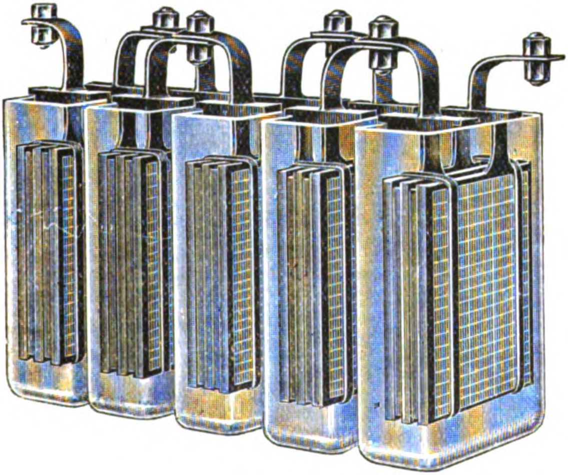

Fig. 358.—Chloride K.X.G. cells.

plates are suspended by their lugs from the sides of the boxes. Both positive and negative plates are pasted, the grids being of the cage type, and as the bars on one face are staggered with those on the other, the active material is in the form of continuous pencils, extending from the top to the bottom of the plate. Grooved wood separators are used, and are kept in position by celluloid bands passing right round the element as shown in the illustration. The cell is thus practically semi-solid, and requires a minimum of attention.

E.P.S. CELLS.

The earlier types of cell made by the Electrical Power Storage Co. were of the Faure or pasted type. The Company's latest type of cell for telegraph and telephone purposes, which is gradually replacing the earlier types, is known as the "S.H." type, Fig. 359.

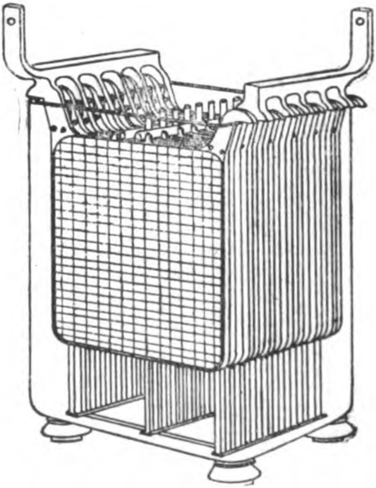

FIG. 359.—E.P.S. S.H. type cell.

The "S.H." positive plate consists of a cast lead grid having a large number of thin vertical ribs strengthened at intervals by horizontal ribs, and supported in the centre by a diaphragm (Fig. 360) in order to enable the plate to withstand buckling in both directions. The plates, which are Planté formed, measure 10⅛ by 9¼ by ·33 inch in thickness, and the subdivision of the metal is such that the surface is very considerably augmented.

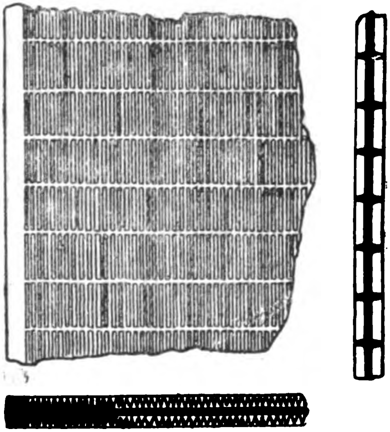

FIG. 360.—S.H. type portion of positive plate. ½ full size.

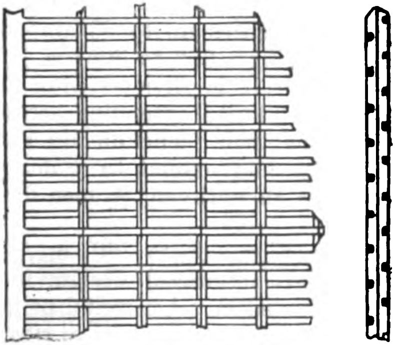

FIG. 361.—S.H. type portion of negative plate. ½ full size.

The negative plate (Figs. 361) is of the pasted type, the ribs on one side of the plate being staggered in relation to those on the other, and is designed so as to provide a large amount of paste.

In Fig. 359 will be seen the general construction of this type of cell, the plates being made so that they hang from the edges of the glass boxes, allowing a clear space beneath the plates for the reception of sediment.

The plates are separated by means of three long glass tubes between each pair, one being placed in the middle, the other being near the outer edges. The tubes are kept in position by small lead nipples which project from the negative plates, and at the bottom of the cell by a lead channel, and the chances of buckling in the plates are thereby reduced.

A 5-plate cell of this type has an output of 119 ampere-hours, or 39½ ampere-hours per positive, when discharged in seven hours.

The internal resistance of a 25-plate cell is only ·00033$^{\omega}$.

HART CELLS.

The Hart cells, which employ a formed positive and a pasted negative, are used by the Post Office amongst other types for all capacities up to 90 ampere-hours.

The positive grid (Figs. 362 to 365) is $\frac{1}{4}$ inch thick, and upon either side it is divided into five vertical divisions, with horizontal ribs extending across the plate and spaced 11 to the inch. The oblong grooves have slightly tapered sides and extend to a depth of about $\frac{3}{32}$ inch on either side, thus leaving $\frac{1}{16}$ inch for the central web of the plate.

The negative grid (Figs. 366 to 369) is $\frac{3}{16}$ inch thick. The type is the Hart interlaced design, in which the active material is divided into horizontal pellets securely caged in position by means of the vertical ribs alternating on either side of the plate, as shown in detail in Fig. 369.

The general appearance of the Hart cell is illustrated in Fig. 370, from which it will be seen that the plates are of the hanging type, suspended from the top edges of the glass boxes and supported at the ends by antimonial lead springs to keep them in position and to prevent them from spreading or buckling. The cells are also connected together by means of a lead alloy coned bolt accurately fitting into a correspondingly tapered hole in the lug ends, thus greatly increasing the area of contact between the terminals. The bolt is not attacked by the acid or acid fumes. The separators are of the glass tube pattern, provided with flanges which rest on the top edges of the plates.

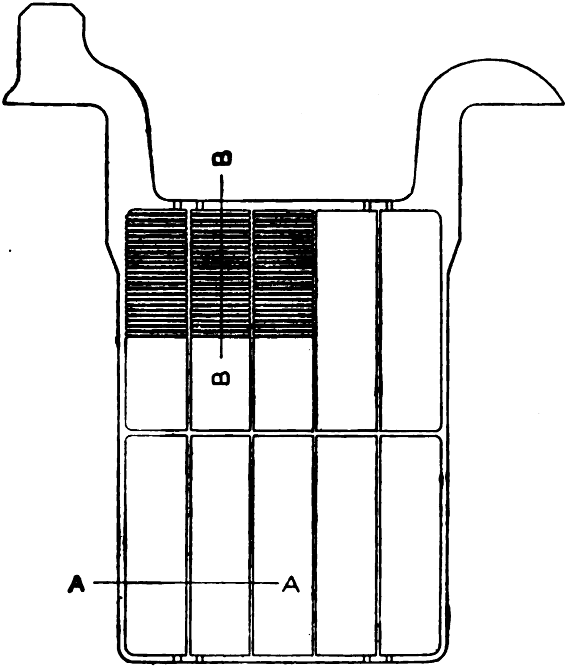

FIG. 362.—Hart positive. ½ full size.

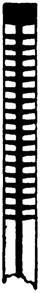

FIG. 363.—¾ of full size section on line BB in Fig. 362.

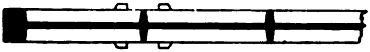

FIG. 364.—¾ of full size section on line AA in Fig. 362.

The 5-plate cells have a capacity of 45 ampere-hours at the nine-hour rate, whilst at the five-hour or maximum rate it is 40 ampere-hours.

The specific gravity of the electrolyte is 1·190 when placed in the cells, and when fully charged it should rise to 1·200. If at the end of the first charge the density is above 1·210, pure distilled water should be added to reduce it to 1·205 to 1·206. The discharge should cease immediately the gravity falls to 1·170.

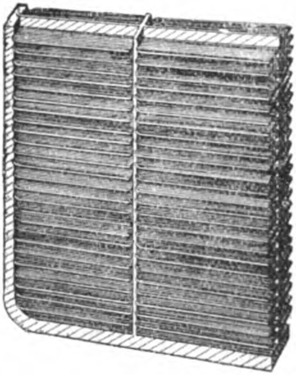

FIG. 365.—Perspective view of a portion of a Hart positive plate.

The 45, 72, and 90 ampere-hour cells have respectively five, seven, and nine plates, each 5½ by 7½ inches. In 18 and 27 ampere-hour cells the plates are 4 by 4 inches.

OTHER TYPES.

The "D.P.," Tudor, and Premier cells are somewhat similar in design, the positives being of the cast Planté type, working with box negatives.

E.M.F. ON CHARGE AND DISCHARGE.

For charging secondary cells the E.M.F. of the dynamo should be from 2·6 to 2·75 volts per cell. The opposing E.M.F. of the battery rises to 2·6 volts per cell at the end of the charge, but upon disconnecting the dynamo the E.M.F. at once falls to rather less than 2·2 volts—in fact, the practical maximum should be regarded as 2·1 volts. During the greater part of the discharge the E.M.F. very closely approximates to 2 volts, and it is only towards the end of the discharge that it falls below this value. After 1·8 volts is reached the E.M.F. falls rapidly, and if the discharge is continued serious injury to the plates will probably result.

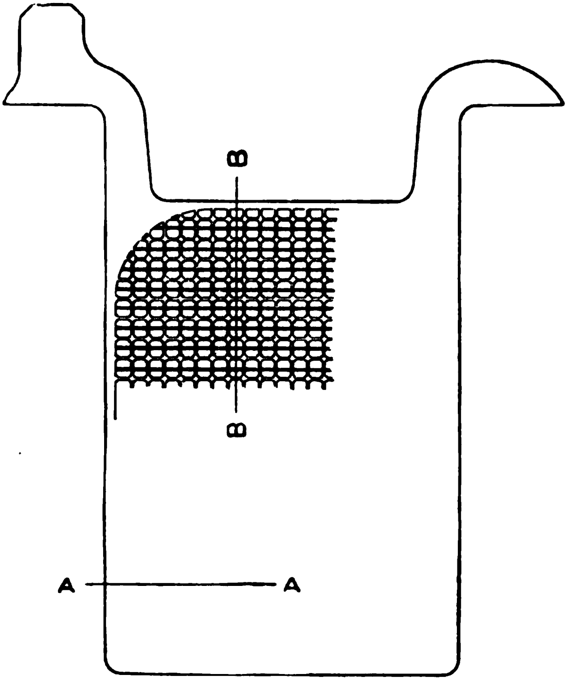

FIG. 366.—Hart negative. ¾ full size.

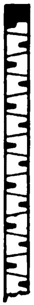

FIG. 367.—¾ full size section on line BB in Fig. 366.

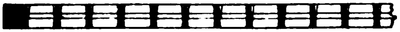

FIG. 368.—¾ full size section on line AA in Fig. 366.

Internal Resistance and Temperature.

The internal resistance of even the smallest type of secondary cell is extremely low. In the E.P.S. K 7 type it is about ·0015$^{\omega}$, whilst in the Chloride R 15-plate type it is but ·00038$^{\omega}$. It is interesting to notice that the internal resistance of the cell decreases as the value of the discharge current rises. The resistance of dilute sulphuric acid is least when the acid is 30 % and water 70 %, or specific gravity 1·224. With 10 % acid the resistivity is 67 % higher and 84 % higher with 60 % acid.

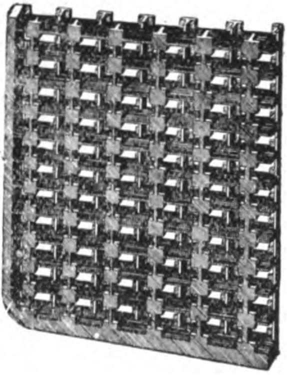

Fig. 369.—Perspective view of a portion of a Hart negative.

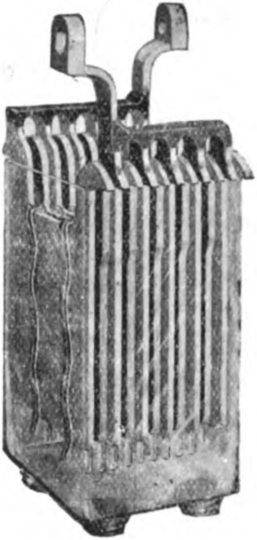

Fig. 370.—Hart cell.

The temperature at which the cell is working also affects the E.M.F., specific gravity, and capacity of a cell. The higher the temperature at which the cell is working the greater the capacity, but working at an abnormally high temperature will seriously reduce the life of the elements. The actual increase in capacity of a secondary cell varies from 1 % to 3 % per 1° C. rise, dependent on the rate of discharge and design of the elements.

INSULATORS.

Large cells are usually placed upon shallow wooden trays filled with sawdust, so as to distribute evenly the weight of the cell and avoid the risk of breakage due to unequal stresses upon the bottom of the glass box. Lead washers placed between the jar and the insulator are occasionally used instead of wood trays. The smaller sizes are supported without trays, while the smallest are often arranged five in one tray.

The racks are usually formed of stout beams of timber with mushroom insulators upon which the trays are placed. The insulator (Fig. 371) consists of two glass castings fitted as shown, but with the lower part partially filled with oil. This prevents the formation of a continuous layer of moisture between the cell and the support, so long as the surface of the oil is free from dirt.

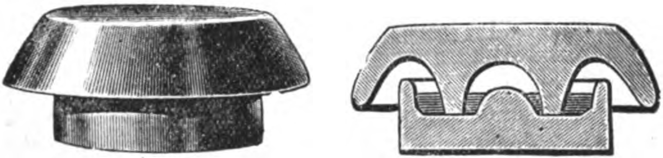

FIG. 371.—Appearance and section of an insulator.

ELECTROLYTE.

Brimstone sulphuric acid having a specific gravity of 1·840 should always be used. The acid should be free from impurities, such as arsenic, nitric, or hydrochloric acid. It should be diluted to the required extent with pure water—preferably distilled. If the water to be used is not soft and free from lime it should be boiled prior to use. When diluting acid it should be borne in mind that the acid should be added to the water and not the water to the acid, since the temperature is kept within better limits. Since the specific gravity of the acid is affected by temperature, a correction of plus or minus ·007 should be made for every degree above or below 15° C. respectively.

TREATMENT OF CELLS.

In erecting a new set of cells the acid should, upon no account, be put into the cells until everything is in readiness for commencing to charge. This first or "initial" charge should preferably continue without intermission for from 36 to 40 hours—in some cases even longer. If it is not possible to arrange this the charge may be stopped after 18 to 24 hours, but current must not be taken from the cells. It will be found that the specific gravity of the electrolyte begins to fall immediately it is placed in the cells, and the first charge is continued until the gravity rises to its full value, and both plates gas freely whilst the solution attains a "milky" appearance. The charging rate for the first twelve hours is usually about one half of the maximum rate. After this period it is increased to the full rate, but, should the negatives fail to gas freely whilst the positives do so, or *vice versâ*, the charging rate is again cut down until this comes right. This initial charge should be continued until the Sp. Gr. remains constant for 4 or 5 hours. This is most important as the future behaviour of the cells depends on the proper completion of the initial charge.

In general, the range of the specific gravity between the charged and discharged conditions is from 30 to 35 points, with a minimum of 1·180 for the discharged condition. When a cell is fully charged the specific gravity ceases to rise, the voltage rises to 2·6 volts and both positive and negative plates gas freely.

The ampere hour efficiency of a battery is obtained by taking the ratio of the current in amperes × time in hours for the charge as compared with the discharge. The watt hour efficiency is a comparison of the energies involved, *i.e.*, the voltage, current, and time are taken into consideration.

The percentage of overcharge necessary to keep the cells in good condition depends to some extent on the amount of work done, that is to say assuming for the sake of argument that a battery is doing no work at all, but is standing on open circuit, occasional charging will be necessary in order to keep the cells in good condition, and therefore the efficiency of the cells, regarded as efficiency, will be low. Similarly, if a battery is getting, comparatively speaking, little work, or if its discharge is at a very low rate, and spread over considerable periods, the amount of charging necessary to keep it in good condition will be more than if the battery was discharged regularly every day to within a reasonable limit of its capacity, but in considering small cells, such as are in general use for telegraph work, satisfactory service is of far more importance than 90% efficiency.

Regular readings of specific gravity before and after charge, and the voltage of individual cells should be taken and recorded and constitute valuable information as to the condition of the cells. It is far better to have early indication of any tendency to failure of an individual cell, than to ascertain by palpable evidence of a drop in voltage if a failure has occurred.

For this reason it is a good practice to look over the cells when they begin to gas to see that they all gas evenly, so that any trouble may be detected and remedied before the charging is completed. When cells are very lightly worked there may be some variation in the specific gravity of adjacent cells, which if it only amounts to a few degrees requires no attention, but should it vary considerably after a gassing charge it may be advisable to adjust the gravity, but it is better to communicate with the makers of the cells before doing so. In order to avoid persistent overcharging which entails excessive gassing and disintegrates the active material, with a consequent accumulation of deposit at the bottom of the boxes and a decrease in capacity and life of the plates, it is well that on ordinary occasions of recharging only about 10 to 15% more should be put into the cells than has been taken out, and at intervals of about two weeks an " overcharge " should be given them, that is to say the charging should be carried to a complete maximum, so as to reduce all sulphate, even up the specific gravity, and keep the plates in good condition. Under some conditions of service, however, it is not necessary to charge so often as once in two weeks, and in such cases each charge becomes an "overcharge," and it is highly desirable when cells are charged at infrequent intervals to make sure that all the conditions of full charge are reached. This can only be ensured by continuing to charge for a comparatively long period after the cells are apparently full, to ascertain definitely whether the voltage and specific gravity have risen to their maximum values. It is desirable that charging should be carried out at or near the normal rate recommended by the makers. Lower rates of charge are open to the objection that the indications of complete charge are not so well defined as when the charge is at the normal rate, and thus the cells are liable to be either overcharged or undercharged.

The various sets of cells used on local circuits are liable to be unequally discharged, and if they are arranged to be charged in series, care should be taken that so far as possible the amount of work which each local set has to do is approximately the same, otherwise with same amount of charging one set may be undercharged and the other overcharged.

The frequent inspections and general amount of attention which were formerly necessary with secondary cells has been largely obviated by the employment of the patented wood separators supplied with the type of cells illustrated in Fig. 356. These form a continuous diaphragm between plates of opposite polarity and entirely prevent any treeing across from the negative plates if properly maintained, which at one time was of frequent occurrence, particularly when cells have been in operation for some years, and moreover there cannot be any internal contacts due to the active material falling away from the grids. As the wood separators in the type illustrated are kept in position by celluloid bands passing right round the element, there is no difficulty in lifting the plates from the cells when the accumulation of deposit has accumulated to an extent which renders washing out desirable. It is important to note that washing out should always be done *before* the deposit touches the bottom of the plates, as should this occur serious injury may be caused to the plates. Care should be taken when the deposit is being removed that the negative plates are not allowed to become dry, and as the cleaning of individual cells is an operation that requires but little time to perform there is no reason why the plates should be out of the acid for more than a few minutes. The level of the electrolyte will require adjusting to compensate for the deposit which has been removed. Should it be necessary to remove the positive plates from the electrolyte, *e.g.* to correct buckling, the cell should first be charged.

Evaporation, and the loss of the electrolyte through charging, should be made good by the addition of water, and it is worth while taking steps to see that the water used for this purpose is suitable. In many towns tap-water contains an amount of hardness which is deleterious to the cells, and in such cases it is preferable that distilled water only should be used for topping up. The level of the electrolyte should be maintained by the addition of *distilled* water above the tops of the plates; about half an inch above the tops when the cells are quiescent is the usual level.

Failure to keep the plates covered gives rise to many troubles apart from the loss of capacity owing to the reduced area of the plates in action. "Topping up" water should be added by a funnel and glass tube to prevent any possible corrosion of the tops of the plates and the lugs resulting from a weak solution of electrolyte at the surface.

With the non-corrodible type of cell to cell connections at present employed the trouble which has been experienced in the past due to the acid fumes attacking the connecting bolts has been quite eliminated.

The best modern practice is entirely opposed to the idea which was at one time prevalent that batteries could be worked satisfactorily in parallel, as experience has proved beyond doubt that parallel working is a method which almost invites trouble.

Where for any reason it is found that the capacity available is insufficient, steps should be taken perhaps by more frequent charging to lessen the demand on the cell over a given period, or to arrange for cells with a larger capacity to be installed. The troubles to be apprehended by installing cells with too large a capacity bear no comparison whatever with the troubles which are likely to be met with if the capacity of the battery is too small.

It frequently happens that in large towns the space available to contain secondary cells for telegraph working is wanting in every attribute which a battery room is supposed to possess, and exigencies of space often demand that the cells should be accommodated as best they can in underground cellars with no light and no ventilation. In such situations it is imperative that the cells should receive careful attention and inspection at frequent intervals and, above all, that as far as possible regular readings should be taken and recorded of the specific gravity, voltage, etc., so that timely warning may be received of any irregularity in their condition.

ADDENDUM.*

The hydrometer gives reliable indication of the state of charge of the cells and the ampere hour capacity remaining in a battery can be determined by multiplying the difference between the specific gravity reading at full charge and at the time of test by the *specific gravity constant* and subtracting the result from the rated ampere hour capacity. The specific gravity constant is the figure obtained by dividing the ampere hour output measured on a test discharge at normal discharge rate by the number of degrees that the specific gravity has fallen during the last discharge.

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* The reader who desires to pursue further the study of secondary cells is referred to Rankin's *Storage Battery Practice* (Sir Isaac Pitman) Chapters I to VI. See also "Secondary Cell Maintenance," by J. G. Lucas, *P.O. Electrical Engineers' Journal*, Vol. VI, pp. 336-342, and "Accumulator" by E. Lack, *ibid.* Vol. XII, p. 143.

CHAPTER XVIII

SECONDARY CELL WORKING.

INTRODUCTORY.

THE use of a separate primary battery for each circuit is a costly method of providing the electrical energy required to work the circuits in a telegraph office of even moderate size. Considerable economy can be effected by joining several circuits to a single group of cells, and this plan is still adopted in the case of very small central battery systems. But, when the number of primary cells used in an office exceeds 300, the provision of secondary cells is generally justified, the energy required for charging purposes being obtained from the town electric light and power mains. Such an installation possesses the advantage of providing a constant and unvarying voltage to each circuit—a matter of considerable importance in the case of Wheatstone and quadruplex circuits. There is a large saving in the cost of the electrical energy as compared with primary cells and also in the space occupied by the relatively small number of secondary cells.

The employment of a common or universal battery involves a number of changes in the connections of the circuits, and as secondary cells are capable of supplying large currents it is necessary to provide fuses to guard against the risk of fire.

Two earthed batteries, one to provide positive, and the other to provide negative, currents are required for circuits which use current in both directions, *i. e.* for circuits worked by single needle or double plate sounder and for double current working generally. Such a circuit thus necessitates the use of twice as many cells in the universal battery as are required if the circuit is worked by a battery devoted to its exclusive use.

The necessity for separate batteries will be apparent from consideration of Fig. 372, in which two up station single needles are joined to a single battery; for, when the keys are depressed as shown, neither station sends out a current owing to the battery being short-circuited by the left commutator earthing the positive, and the right commutator the negative, pole of the battery. Had one of the stations been up and the other down, the same result occurs when both right, or both left, keys are depressed. It will also be recognized that neither can up and down single current sounders be worked by the same single battery.

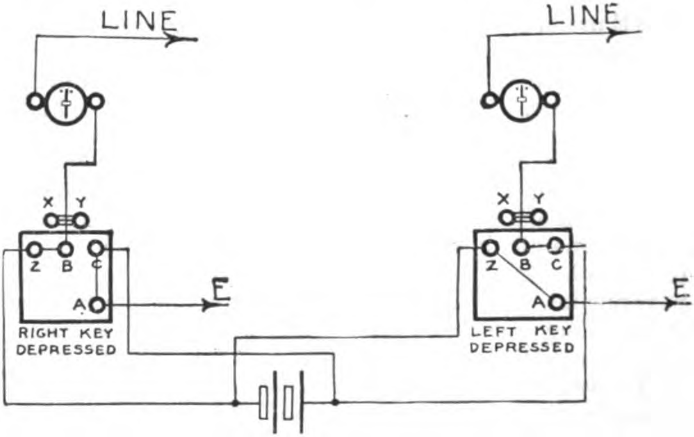

FIG. 372.—Battery short-circuited when connected to two single needles.

The sending apparatus on circuits using both directions of current is therefore modified so that one position of the key or keys joins the positive, whilst another position connects the negative, battery to line. Every class of circuit worked from a universal battery is, therefore, in skeleton equivalent to the three single current sounder, sending circuits shown conventionally in Fig. 373, viz. to a battery joined to a number of circuits in parallel. The essential condition for satisfactory working is that, since the number of circuits over which current is flowing varies from instant to instant according to the position of the keys of the various circuits using the battery, the current in any circuit must be approximately the same (i) when it alone is taking current, and (ii) when all the circuits connected to the battery are also closed simultaneously. This condition can be obtained only when the internal resistance of the battery is small in comparison with the joint resistance of all the circuits connected to the battery, and when also the battery is capable of supplying the full current required when all the circuits are working simultaneously. Both these conditions are fully satisfied by a secondary battery, and the size of the cell chosen depends solely on the quantity of energy required for a given period. If the cells are too small it might be necessary to charge them two or three times a day, whereas the general practice is every fourth day.

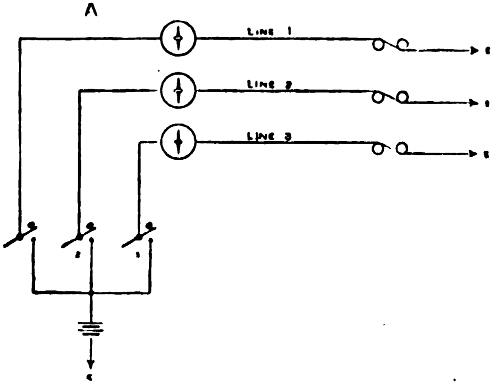

FIG. 373.—Principle of universal battery working.

If the battery shown in Fig. 373 has negligible internal resistance the current flowing in any one of the circuits will have precisely the same value whether one or both the other keys are also depressed or not.

THEORY OF SYSTEM.

When a single primary battery is employed to work several circuits the value of the current in each varies in accordance with the number of keys which are simultaneously depressed. If this variation of current is large the working is unreliable.

If ten single current circuits each having a resistance of 1000$^{\omega}$ are connected to a single battery, having an E.M.F. of 25 volts and an internal resistance of 100$^{\omega}$, the current flowing through each circuit when all the keys are depressed is—

$$\tfrac{1}{10} \text{ of } \frac{25}{100 + \frac{1000}{10}} = 12{\cdot}5 \text{ m.a.}$$

If but one key is depressed, the value of the current in that circuit is—

$$\frac{25}{100 + 1000} = 22{\cdot}7 \text{ m.a. approx.}$$

It will therefore be evident that the current in any of the circuits will vary between 12·5 m.a. and 22·7 m.a. according to the number of keys which happen to be simultaneously depressed. This represents a variation of 55%, which would, of course, render satisfactory working quite impossible.*

* The following formulæ are frequently useful:—

Let E = E.M.F. of battery.
r = internal resistance of battery.
E_1 = Potential difference when all the circuits are working.
E_2 = E.M.F. lost in battery.
a = resistance of one of a number of circuits, which may be of unequal resistance, connected to the battery.
R_1 = joint resistance of all the circuits connected to the battery.
C_a = current in the circuit of a^{ω} resistance.

$$E_1 = \frac{R_1}{r + R_1} \text{ of } E,\ E_2 = \frac{r}{r + R_1} \text{ of } E, \text{ and } C_a = \frac{E_1}{a}$$

If p = current in the circuit of a^{ω} resistance when all the circuits are working expressed as a percentage of the current in a when it only is working:—

It will now be well to consider the battery replaced by one of the same E.M.F. but having absolutely no internal resistance. In this case the current in each circuit is always 25 m.a. no matter whether this is the only circuit having its key depressed or whether all the keys are simultaneously depressed.

In the latter case the joint resistance of the ten circuits is 100^{ω} and the total current sent out by the battery is 250 m.a., but this divides equally between them, thus giving 25 m.a. in each. When one key is depressed the resistance which the battery encounters is 1000^{ω} and the current is therefore 25 m.a. as in the previous case. In other words, the circuits have absolutely no effect upon each other, and this represents the ideal condition.

UNIVERSAL WORKING WITH PRIMARY BATTERIES.

When primary cells are used to form a universal battery the internal resistance is of vital importance, and its value for satisfactory working must never exceed half the joint resistance of all the circuits connected to it. In general not more than five or six circuits are connected to a primary cell universal battery. Moreover, the resistances of the circuits connected should not differ by more than 25%. Should this case arise resistance blocks are inserted in the battery leads to the instrument. The resistance inserted should, however, only be of sufficient value to bring up the resistance of the circuit to within 25% of that of the highest circuit connected.

$$p = 100 \left\{ \frac{1 + \dfrac{r}{a}}{1 + \dfrac{r}{R_1}} \right\} \text{(i) or, } p = 100 \left\{ \frac{R + r}{R + n r} \right\} \text{(ii)}$$

when n circuits each of equal resistance R are connected. Also,

$$n = \frac{100}{p r}(R + r) - \frac{R}{r} \text{ and } r = \frac{R\,(100 - p)}{p n - 100}.$$

PART I.—POWER ARRANGEMENTS.

The switching arrangements about to be described owe their origin to Major T. F. Purves.

VOLTAGES REQUIRED.

The value of the E.M.F.s required to work all the circuits in a large telegraph office differ very considerably, but it has been found that practically the whole of the conditions are met by providing four positive voltages, 24^v, 40^v, 80^v, and 120^v, and four negative, 24^v, 40^v, 80^v, and 120^v.

With the exception of small central battery systems where Leclanché No. 0 cells are used, universal battery working with primary cells is now very rare. In no case should long simplex or long duplex, quadruplex or high speed circuits be worked from a universal primary battery.

24-VOLT SETS.

The installation of secondary cells may be divided into two distinct groups, respectively termed the "main" and "24-volt" batteries. The latter is used to work the local circuits (900^ω sounders being employed) and to provide main battery power for all the sub-office or other minor circuits for which 24 volts is sufficient. Since these circuits are usually more numerous than longer ones, and the battery also provides current for all local circuits, a larger type of cell than is employed upon the main sets is frequently required. The local circuits are divided into two approximately equal groups, one being worked by 24^v positive and the other by the 24^v negative battery.

In order to provide for the re-charging of the cells, and also to ensure a stand-by in case of failure or accident, the battery is provided in duplicate. The 24^v set therefore consists of 48 cells or four groups of 12 cells, thus providing 24^v positive and negative and two groups spare.

MAIN SETS.

The main battery consists of eight groups of 20 cells each, two groups of which are always spare. The complete installation is shown diagrammatically in Fig. 374. It is important to notice that the groups of cells will not be worked evenly since the last sets of cells forming the 120^v lead are only called upon to supply current for the circuits requiring that E.M.F., whereas the inner sets supply all circuits requiring 40^v and, in addition, provide current for those requiring 80 and 120^v. The groups providing 40^v are therefore worked more heavily than those providing 80^v or 120^v, and similarly the groups providing 80^v are more heavily worked than those providing 120^v. Hence inner cells would become discharged before the outer ones. In order to secure uniformity of output, from the different main groups of cells, a novel and interesting form of Rotary Switch was devised in 1902 by T. F. Purves, for the purpose of interchanging the positions of the groups. Each set, after being charged, supplies for the first day 40^v, for the second 80^v, for the third 120^v, whilst upon the fourth day it is again thrown spare for charging.

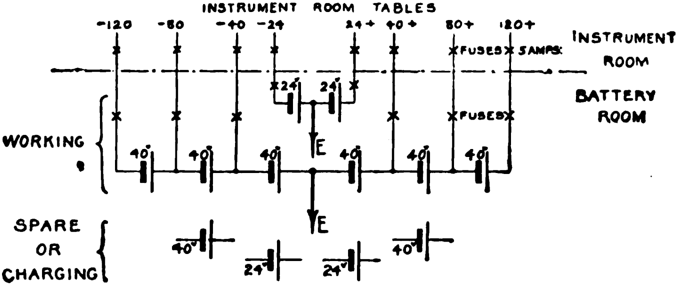

FIG. 374.—Complete installation of secondary cells.

Two switches are employed, one of which deals with the positive and the other with the negative groups. Each switch has four positions corresponding with the four ways in which the cells may be joined up. The connections formed in each position of the negative switch are shown in Fig. 375. The positive switch is similarly arranged. The arrangement will be quite apparent from the comparison of Figs. 374 and 375 with the table given at the top of page 588.

TABLE SHOWING CONNECTIONS OF THE MAIN SETS.

Negative sets.					Positive sets.				
Position of switch.	No. of set connected to				Position of switch.	No. of set connected to			
	On charge.	120^{v}.	80^{v}.	40^{v}.		40^{v}.	80^{v}.	120^{v}.	On charge.
No. 1 1st day	1	2	3	4	No. 1 1st day	4	3	2	1
No. 2 2nd day	2	3	4	1	No. 2 2nd day	1	4	3	2
No. 3 3rd day	3	4	1	2	No. 3 3rd day	2	1	4	3
No. 4 4th day	4	1	2	3	No. 4 4th day	3	2	1	4

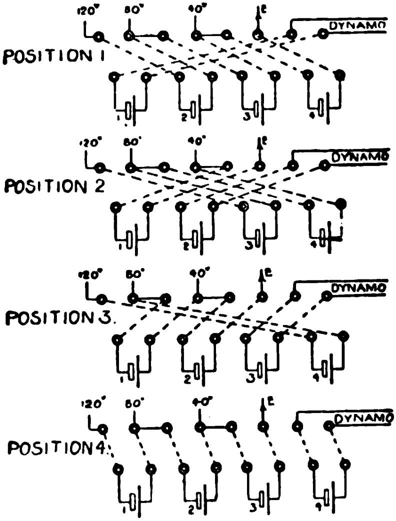

FIG. 375.—Connections of cells in each position of the main switch.

GENERAL SCHEME OF FUSES.

The use of secondary cells entails the provision of fuses, since large currents may readily result from the presence of faults. These excessive currents may seriously injure the cells and also might quite easily produce a fire were precautions not taken to prevent the continuous passage of current of abnormal value. A 20-ampere fuse is inserted at the cells in the leads to the "switch cabinet," and 5-ampere fuses are placed in the leads at the "main distributing cabinet" in the instrument room. After passing these fuses the leads go to the various "distribution and fuse cases" upon the tables. At these points 1-ampere glass tube fuses are inserted between the main leads and the instruments themselves. Every instrument is represented by a fuse upon this case, and it is therefore impossible for a fault upon one instrument to blow a main fuse and temporarily thus stop the working of every circuit using the voltage in question. The general scheme is sufficiently indicated in Fig. 376.

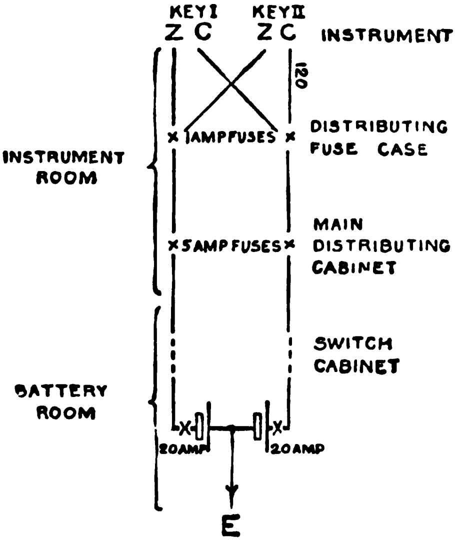

FIG. 376.—General principle of application of fuses.

BATTERY ROOM.

The battery room should be of ample size, and good ventilation is necessary owing to the acid spray which pervades the atmosphere whilst charging is proceeding and which, in a confined space, is explosive. The room should be cool (temperature of from 50° to 80° F.); it should be well lighted (preferably daylight) and wall plugs fixed for the connection of hand lamps. It is essential that the windows should be frosted or painted where necessary to prevent the direct rays of the sun from falling upon the cells. Also, it is inadvisable to have Leclanché cells in the room owing to the ammonia liberated. The cells are carried upon trays and insulators, as previously described, resting upon white pine racks, varnished or painted with acid-resisting paint, and placed so that the edges of the plates can be inspected from both sides. The floor of the room should be of acid proof asphalte, blue brick set in mastic cement, or if a wooden floor it should be covered with sheet lead, the various seams of which are burned (*not* soldered) and having the edges turned up for 2 inches or 3 inches round the outsides, a suitable fillet being used to provide space for the opening of the door. In no circumstances should cells be placed in a room having a plaster ceiling.

The ideal method of connecting the cells together is by lead burning, so dispensing with bolted connections. The disadvantage is that to remove a cell entails cutting the connections. In telephone installations, where the battery is used to provide "speaking" power, the connections between the cells are invariably burnt together, but for telegraphic purposes the same need for keeping the resistance of the battery down to the lowest possible limit does not exist. The Hart Company provide a bolt and nut made of a lead alloy which is not affected by the acid spray. Other makers employ brass nuts and bolts, and trust to the layer of acid-resisting paint with which they are covered for protection.

MAIN FUSES AT THE CELLS.

The leads are taken from the cells to a grooved casing running along the side of the racks, but before entering the casing a fuse is inserted. This fuse consists of a circular fibre tube with a suitable slot to give access to the fuse wire, which is of silver. The cables are seven strands of No. 16 copper wire, insulated with paper, impregnated with resin oil, and covered with a seamless sheathing of lead. The cable is connected to the fuse by means of a thimble connector and a brass sleeve, the latter being soldered on to the lead covering of the cable as illustrated in Fig. 377.

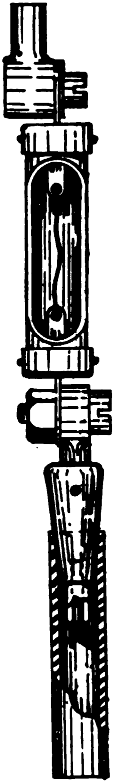

FIG. 377.—Method of terminating cables and fuse at the cell.

SWITCH CABINET.

From the cells the leads pass on to the switch cabinet, which is also placed in the battery room. Dealing with the 24-volt sets first, it will be seen (Fig. 378) that the leads pass to the centre of points of four double-pole two-way switches. With the switches in the positions shown sets 1 and 3 are connected to the 24^v leads to the instrument room with the junction of the sets earthed, whilst sets 2 and 4 are connected in series to the dynamo through the 48^v charging switch (Fig. 379). Sets 1 and 2, which provide the negative voltage, are interchangeable, as are the positive voltage sets 3 and 4.

DETAILS OF POSITIVE AND NEGATIVE SWITCHES.

The positive and negative main rotary switches already referred to are of a far more complicated character, since three-fourths of the cells are working whilst the remaining fourth is spare or is being charged. Although the sequence of operations performed by the switches is complex, their manipulation is exceedingly simple and their design is such that, even while the switch handle is being moved, the power supply remains continuously connected to the instrument room. This is effected during the motion of the switch by placing two sets in parallel on to the various main leads successively until, finally, the set of cells due to be charged is disconnected from the working circuits and is moved on to the charging leads. The connections of the positive and negative switches are identical, and the latter is illustrated diagrammatically in Fig. 380. The moving member of the switch consists of a commutator barrel upon which are placed eight continuous rings connected to eight series of segmental blades bearing similar numbers to those of the continuous rings. Upon the base of the switch are mounted two sets of eight brushes, connected as shown, making contact with the rings and segmental blades. The commutator is revolved to make the various changes, the brushes

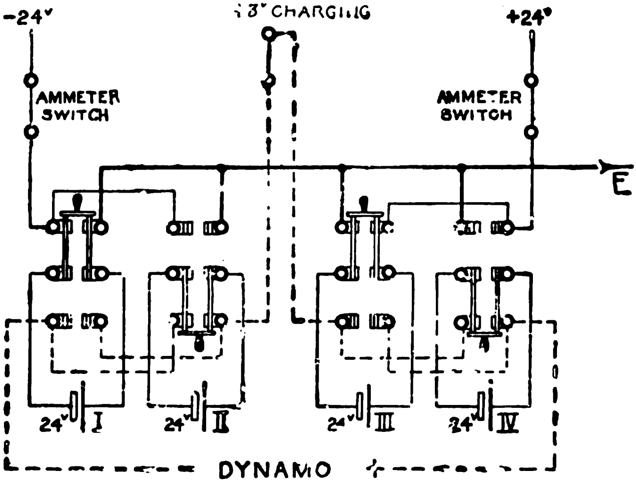

Fig. 378.—24v battery switches.

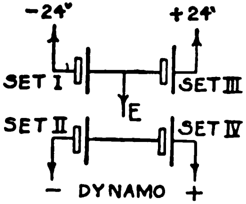

Fig. 379.—Skeleton connections of Fig. 378

remaining stationary. The main switches are operated by means of a removable handle (not shown in Fig. 382) upon the side of the cabinet. From Fig. 380 the various changes may readily be traced. It will be noticed that the blades and brushes connecting to the circuit of the charging dynamo are made specially narrow. This is in order that the first operation of the switch, during its traverse, shall be to disconnect the dynamo from the freshly charged set of cells, while its last operation is to reconnect it to the exhausted set. In order to render the arrangement quite clear, the sequence of the various changes is tabulated—

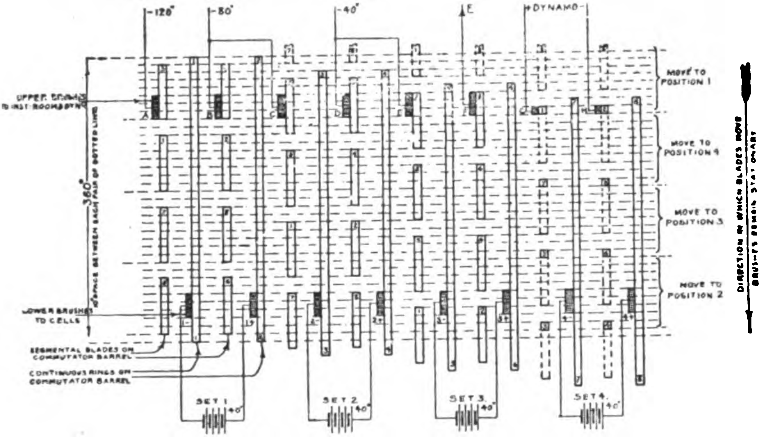
-120°
-80°
-40°
E
DYNAMO
UPPER BRUSHES TO INST. ROOM BSTN
360° SPACE BETWEEN EACH PAIR OF DOTTED LINES
LOWER BRUSHES TO CELLS
SEGMENTAL BLADES ON COMMUTATOR BARREL
CONTINUOUS RINGS ON COMMUTATOR BARREL
SET 1
SET 2
SET 3
SET 4
40°
MOVE TO POSITION 1
MOVE TO POSITION 4
MOVE TO POSITION 3
MOVE TO POSITION 2
DIRECTION IN WHICH BLADES MOVE
BRUSHES REMAIN STATIONARY

FIG. 380.—Connections of the rotary drum switch for the negative main sets.

FOUR POSITIONS OF SWITCH.

Position I. = 1 to G, 3 to A, 5 to C, and 7 to E.				Position II.—at 90° = 1 to E, 3 to G, 5 to A and 7 to C.			
First move				*Second move*			
after 10°	1 Breaks from	G		after 100°	3 Breaks from	G	
,, 20°	1 Makes on		E	,, 110°	3 Makes on		E
,, 30°	7 Breaks from	E		,, 120°	1 Breaks from	E	
,, 40°	7 Makes on		C	,, 130°	1 Makes on		C
,, 50°	5 Breaks from	C		,, 140°	7 Breaks from	C	
,, 60°	5 Makes on		A	,, 150°	7 Makes on		A
,, 70°	3 Breaks from	A		,, 160°	5 Breaks from	A	
,, 80°	3 Makes on		G	,, 170°	5 Makes on		G

Position III.—at 180° = 1 to C, 3 to E, 5 to G and 7 to A.					Position IV.—at 270° = 1 to A, 3 to C, 5 to E and 7 to G.				
Third move					*Fourth move*				
after 190°	5	Breaks from	G		after 280°	7	Breaks from	G	
,, 200°	5	Makes on		E	,, 290°	7	Makes on		E
,, 210°	3	Breaks from	E		,, 300°	5	Breaks from	E	
,, 220°	3	Makes on		C	,, 310°	5	Makes on		C
,, 230°	1	Breaks from	C		,, 320°	3	Breaks from	C	
,, 240°	1	Makes on		A	,, 330°	3	Makes on		A
,, 250°	7	Breaks from	A		,, 340°	1	Breaks from	A	
,, 260°	7	Makes on		G	,, 350°	1	Makes on		G

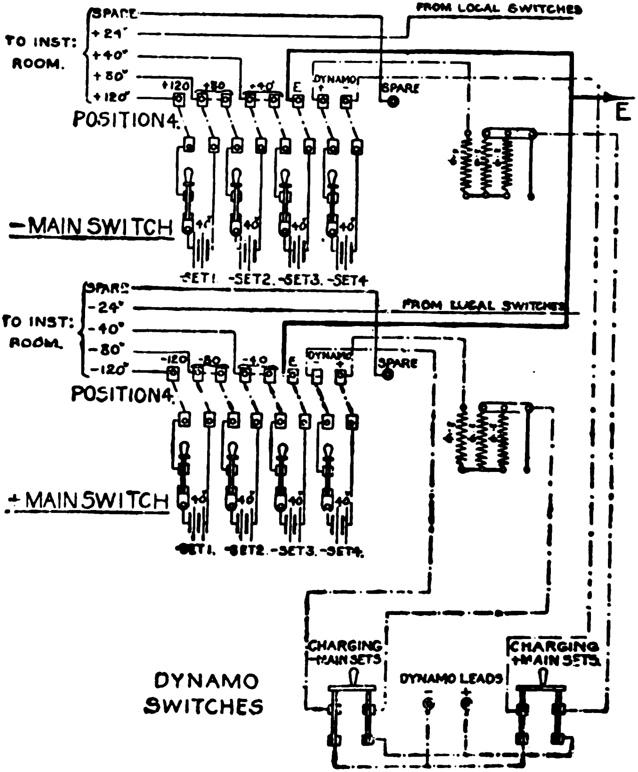

Fig. 381.—Main charging switches.

MAIN CHARGING SWITCHES.

The main charging switches and the general arrangement of the positive and negative main switches are shown in Fig. 381. The dotted connections between the cells and the main leads to the instrument room show the main positive and negative switches each in the fourth position, but these connections are as shown in Fig. 375 if the switches occupy any one of the three other positions.

The charging leads pass through the two double-pole switches (one for the positive and one for the negative main sets) through an adjustable resistance on to the positive and negative main switches. Finally, in series with each set of cells a single-pole switch is inserted.

The resistance mentioned is of bare wire and may be connected up so as to give resistances of $\frac{2}{3}^{\omega}$, 1^{ω} and $1\frac{1}{3}^{\omega}$, and enable the 40^{v} sets to be charged in parallel with two 24^{v} sets. The object of the resistance is solely to take up the difference of 8^{v} which exists between the E.M.F.s of the sets.

The general appearance and arrangement of the switch cabinet is indicated in Fig. 382.

MAIN DISTRIBUTING CABINET.

From the switch cabinet the leads pass to the main distributing cabinet in the instrument room. Here the leads pass through U-links and 5-ampere fuses of the same type as those illustrated in Fig. 377, but with a finer wire. A voltmeter is also provided for testing purposes, and is placed within the cabinet behind the glass door. The general appearance and arrangement of the cabinet will readily be perceived from Fig. 383.

There is space for two additional leads beyond 120^{v}, and these voltages when required are formed by adding ordinary primary cells until the required voltage is obtained. The cases are usually so few that the provision of secondary cells is not warranted.

The cabinet illustrated provides for two separate sets of leads to the tables, and thus enables the office to be divided into two halves. In very large offices the division

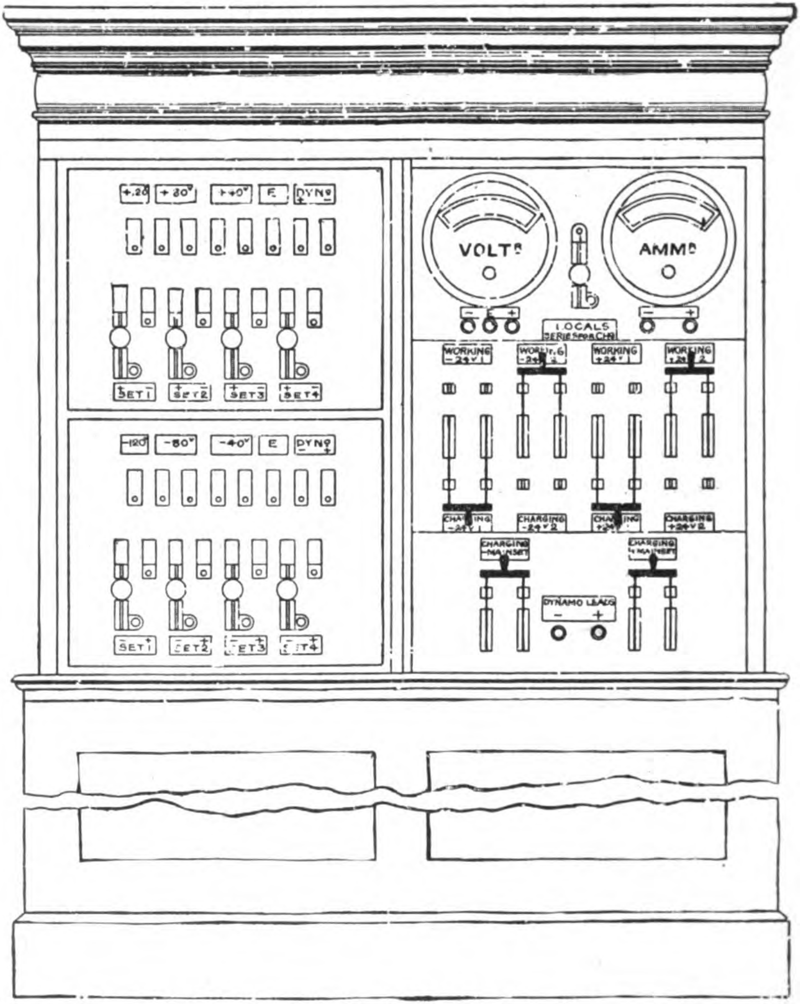

FIG. 382.—Switch cabinet

(Main Rotary Switch Panels on left; 24-volt Switches and Instruments on right)

is sometimes carried further, and more than two tablets are provided, whilst for small offices but half the provision shown is required, and a single set of leads run round the whole of the instrument room.

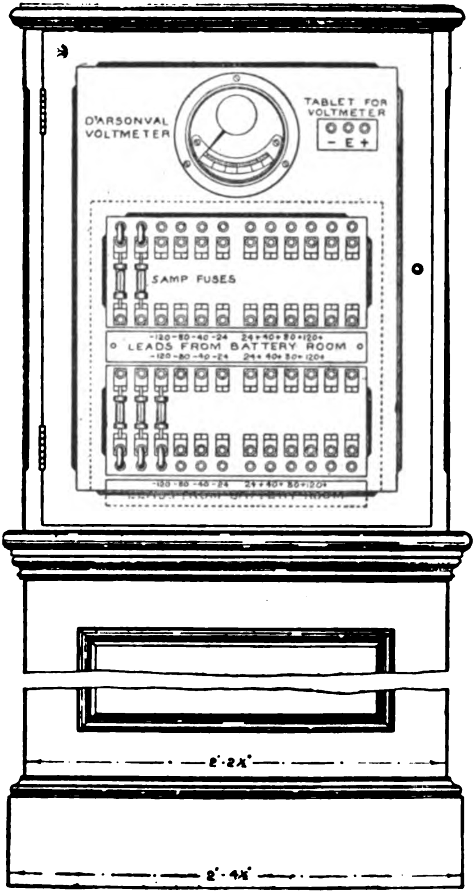

Fig. 382.—Main distributing cabinet.

DISTRIBUTION AND FUSE CASE.

A distribution and fuse case is provided for every three tables, and is placed upon the end of the central table, but with the front in the opposite direction to the front of the instruments. The power leads are tapped off below the floor-line, and are carried to the case in an iron troughing. The power lead is bared by removing the lead sheathing, and impregnated paper and a similarly stripped length of cable is then soldered on to the power lead; the whole is then carefully insulated and covered by a shaped piece of lead sheet securely soldered so as to form an air and water tight joint.

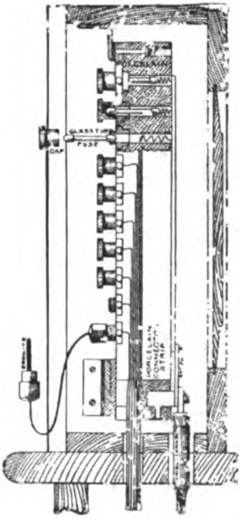

Fig. 384.—Section of distribution and fuse case.

The tablet (Figs. 384 and 385) provides for 80 fuses—*i. e.* ten for each voltage, but by altering the connecting straps which normally join the power leads through to the cut-out strips from the vertical to the horizontal position, sufficient flexibility is obtained to meet most requirements, but in some cases a 100 fuse tablet has to be employed.

The base of the case is of porcelain, with suitable holes for the insertion of the fuses. The brass strip which closes the back of each hole is connected to the particular voltage supplied by that strip. Upon this strip a spiral spring (Fig. 384) is placed so as to press upon and make satisfactory contact with the end of the glass-tube fuse (see Chapter XX, p. 703) which normally rests upon it. The other end of the fuse makes contact with the inner part of the screwed brass cap which normally holds it in position. The base on to which the cap screws is connected to the instrument leads of the circuit to which it is attached, and thus a fuse is inserted in every lead from the case to the instruments. The fuses are of the usual glass-tube pattern with 2-mil platinum wire which fuses at 1 ampere.

Under normal conditions the fuses are not visible, and to examine them it is necessary to remove the brass cap (which at once disconnects the power from the instrument) and remove the fuse.

Special cords are used for changing the power supplied to a circuit having a fuse cap at one end and a fuse cap with an ebonite insulated connector at the other, the fuse cap and fuse are removed from the circuit in question, and their place is taken by the connector, the cap of which is screwed into position. The other end of the cord is then connected in the ordinary way to any spare position on the voltage required, a fuse being of course inserted at this point.

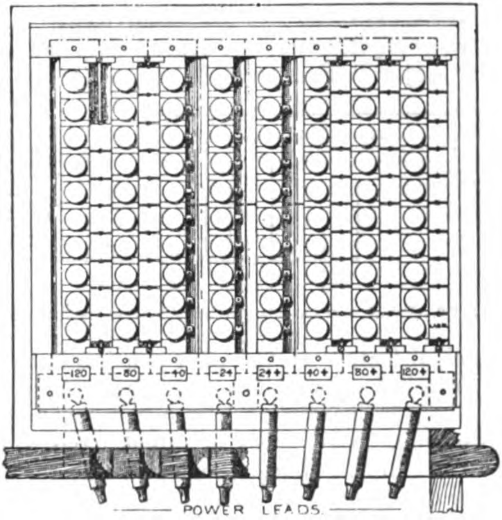

FIG. 885.—Front view of distribution and fuse case.

ORIGINAL SECONDARY CELL INSTALLATION.*

In the original secondary cell system, which was devised by A. J. Stubbs, the cells were duplicated. Equality of work on the groups supplying the higher and lower voltages was obtained by changing their positions with the aid of a reversing switch. The next point of difference consists in the use of a test hole tablet on each table whence leads were taken to fuses contained in a box at each set on the table.

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* The arrangements, now obsolescent, are described in some detail in the earlier editions of the present work.

SECONDARY CELL-WORKING FOR SMALL OFFICES.

The standard arrangements with the costly rotary switch cabinet cannot economically be justified at small offices, and in these cases a simplified method of secondary cell working, designed by Major T. F. Purves, is adopted.*

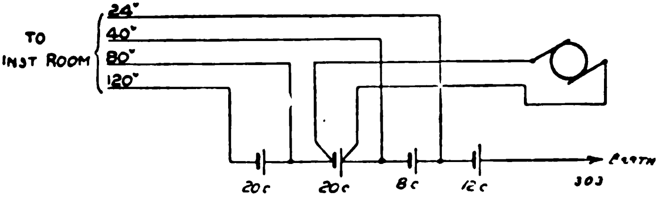

FIG. 386.—Principle of secondary cell-working for small offices.

The principal feature of the plan consists in providing only a single set of cells and in charging each group providing a voltage, separately when necessary, whilst the cells are working. Two types of tablet have been provided for fitting in the charging cabinet, one for six, and the other for eight voltages. The latter type is shown in Fig. 387, and it will be observed that the leads from each cell pass through U-links to the power-leads to the instrument room, where they are connected to distribution and fuse cases. In addition an extra pair of test holes is provided for each lead, so that the charging current may be applied to any particular group of cells by inserting a double U-link plug between the + and − dynamo test holes and the upper battery test holes. The plug is furnished with a guide pin which makes it impossible to place the plug between two groups of cells and thus produce a short-circuit. In the event of the failure of a group of cells the dynamo is inserted in their place and the U-links connecting the particular group withdrawn.

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* "New Secondary Cell System," by R. Halton, *Post Office Electrical Engineers' Journal*, Vol. III. p. 339.

The 24-volt leads are duplicated through U-links to provide also power for telephone speaking and signalling. As the 24-volt lead is taken from the 40-volt group it is necessary to arrange for independent charging of this section, and a suitable resistance unit for taking up the excess voltage of the dynamo is provided; but if the dynamo has at any time to replace the 24-volt set its E.M.F. must be reduced to 24 volts by increasing the resistance in the field-magnet circuit.

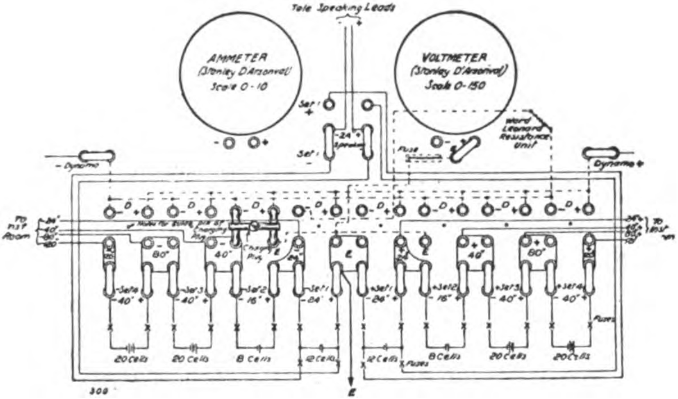

FIG. 387.—Secondary cell charging cabinet with 8-voltage tablet.

The six-voltage tablet is similar to that just described, save that the 24-volt lead is omitted and voltages of 40, 80, and 120 positive and negative only are provided.

The voltmeter and ammeter are employed as in the ordinary system. It may also be added that the automatic cut-out employed in the circuit of the charging dynamo and the cells is of a somewhat simpler pattern than that shown in Fig. 388.

CHARGING ARRANGEMENTS.

Before discussing the charging arrangements it is necessary to indicate how Ohm's law may be applied to a circuit consisting of a dynamo charging a battery of secondary cells. If the opposing E.M.F. of the cells is e volts whilst E is the E.M.F. of the dynamo, and R the total resistance of the circuit, the resulting current C is obtained thus—

$$C = \frac{E - e}{R}$$

The opposing or back E.M.F. of the battery is 2·1 volts per cell at the beginning of the charge, whilst at the end it will have risen to 2·5 volts per cell.

Example.—It is required to charge 25 cells from a dynamo having an E.M.F. of 100^{v} and a resistance of $\cdot 02^{\omega}$. If the charging current is to be maintained at 15 amperes, what resistance must be inserted in the circuit at the beginning and at the end of the charge? The resistance per cell is $\cdot 0015^{\omega}$ and the resistance of the leads $\cdot 02^{\omega}$—

Internal resistance of cells . $\cdot 0015 \times 25 = \cdot 0375^{\omega}$
Resistance of dynamo . . . $= \cdot 02^{\omega}$
Resistance of leads, fuses, etc. $= \cdot 02^{\omega}$

Total resistance of circuit . . $= \cdot 0775^{\omega}$

Back E.M.F. at beginning of charge $= 2{\cdot}1^{v} \times 25 = 52{\cdot}5^{v}$
„ „ end „ „ $= 2{\cdot}5^{v} \times 25 = 62{\cdot}5^{v}$

$$\text{Current} = \frac{\text{Charging E.M.F.} - \text{Back E.M.F.}}{\text{Total resistance}}$$

$$\text{or} \qquad = \frac{\text{Effective E.M.F.}}{\text{Total resistance}}$$

At the beginning of the charge, effective E.M.F. = $100^{v} - 52{\cdot}5^{v} = 47{\cdot}5^{v}$.

$$\frac{E}{C} = R \therefore \frac{47{\cdot}5}{15} = 3{\cdot}16^{\omega}.$$

Resistance to be inserted at beginning of charge—

$$= 3{\cdot}16 - \cdot 0775^{\omega} = 3{\cdot}09^{\omega} \text{ approx.}$$

Similarly, at the end of the charge the resistance to be inserted $= 2{\cdot}45^{\omega}$ approx.

Example.—It is required to charge two batteries of respectively 20 and 24 cells in parallel at 10 amperes each. What resistance will be required to be added to the smaller battery if the E.M.F. of the dynamo is 65^v?

$$\text{Resistance of circuit of larger battery} = \frac{65 - 24 \times 2\cdot5}{10}$$

$$= \cdot5^\omega$$

$$\text{Resistance of circuit of smaller battery} = \frac{65 - 20 \times 2\cdot5}{10}$$

$$= 1\cdot5^\omega$$

$$\text{Additional resistance} = 1\cdot5 - \cdot5 = 1^\omega.$$

This problem illustrates the calculation of the resistance required to reduce the voltage applied to the main sets (see page 595).

PROVISION OF CHARGING CURRENT.

In most towns a supply of electrical energy is obtainable from the town mains, but, as the voltage required to charge the cells is about 60^v, direct charging from the mains is economical only in those few cases in which a continuous current supply at from 85^v to 115^v is available. In such cases a bare wire rheostat with 20 points having a total resistance of 22^ω is employed to regulate the charging current. At repeater stations, which are situated in comparatively small villages, an oil-engine driving a dynamo provides both lighting and charging current.*

Usually the pressure of continuous current supply is either 200^v to 240^v or 400^v to 480^v, and in this case a motor-generator, consisting of a motor driven from the mains coupled to a dynamo, is employed. The motor switchboard contains a double-pole switch, cut-outs, and the motor-starting switch, whilst the dynamo board carries the electromagnetic cut-out (*q.v.*), the field resistance for regulating the voltage, a voltmeter, an ammeter for measuring the charging current, and a pair of cut-outs.

Where a special dynamo or motor generator is employed it is more economical to regulate the charging current by varying the E.M.F. of the dynamo than to insert resistance between the machine and cells. For this purpose a rheostat is placed in series with the field magnet coils of the dynamo, the introduction of resistance reducing the flux through the armature and consequently the E.M.F. generated. The excitation may be varied within fairly wide limits without seriously affecting the efficiency of the machine.

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* "Power supply at a repeater station," by E. A. Lakey, *P.O. Electrical Engineers' Journal*, Vol. II. p. 198 *et seq.*, gives a detailed account of the arrangements.

An alternating current supply may be single, two, or three phase, and in such cases a motor generator is almost invariably employed, but in exceptional cases where the cells are of small capacity a rectifier might be used. With the aid of a transformer the alternating current can be reduced to any desired value. The alternating current may be passed through an electromagnet the polarized armature of which reverses with the current, and with suitable contacts the connections of the supply to the cells are reversed so as to provide a unidirectional current. There are also several other types of rectifier suitable for small installations.*

ELECTROMAGNETIC CUT-OUTS.

If, from any cause, the dynamo were to stop, the cells would immediately commence to discharge themselves through the machine, and serious damage to both the cells and the machine would probably result. This possibility is obviated by the use of the "electromagnetic cut-out," which is included in the circuit between the cells and the machine. Immediately the charging current falls to zero or reverses, the cut-out breaks the main circuit. In some forms the instrument also operates when the current rises above a certain value determined by adjustment.

The form of cut-out generally used, shown in Figs. 388 and 389, consists of an electromagnet having two windings acting upon a movable polarized armature, mechanically attached to which is a ∩-shaped conductor normally resting above a pair of mercury cups placed in the main circuit. The armature lies within the 2000^{ω} polarizing coil *P*, joined directly across the cells, and its upper end is therefore of S. polarity. The 700^{ω} difference coil *D* wound on the left limb of the electromagnet is energized by the current flowing from the dynamo via the cells and polarizing coil, *i.e.* by the current due to the difference between the E.M.F.s of the dynamo and cells. The counter weight on the armature is adjusted so that only when the dynamo E.M.F. exceeds that of the cells by 5^{v}, the polarity induced is sufficient to repel the armature to the right and thus to complete the main circuit by means of the ∩-conductor. When this happens the main or charging current flows through the $\cdot 1^{\omega}$ coil, and tends to hold the armature to the right. Immediately the current fails or reverses, this coil, which produces a powerful field, repels the armature and breaks the circuit.

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* Ampere rectifier (now made by Muirhead & Co.), *Electric Wiring*, by Perren Maycock, p. 429. Nodon valve (an electrolytic rectifier), *Electric Light and Power Distribution*, by Perren Maycock, Vol. II. p. 573. Cooper & Hewitt, mercury vapour rectifier. *Electric Wiring*, by Perren Maycock, p. 344.

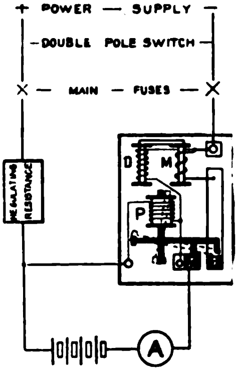

Fig. 388.—Electromagnetic cut-out connections.

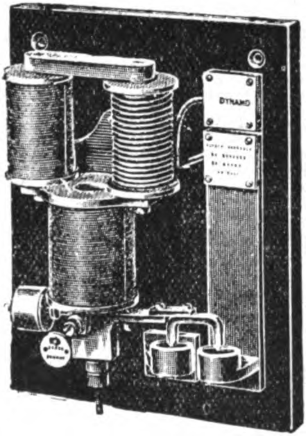

Fig. 389.—Electromagnetic cut-out.

It will therefore be seen that the device automatically cuts in the dynamo when its E.M.F. exceeds that of the cells by 5 volts, and that it breaks the circuit instantly the current reverses, due to the cells discharging back through the dynamo.

SIZE OF CELLS.

The capacity (A) of the main cells is given by the following formula determined experimentally—

$$A = \frac{4\,C\,(t_1 + t_2)}{N}$$

where C = the sum of the line currents required for every circuit requiring *over* 24^v if worked simultaneously.

t_1 = the sum of the times (in hours) during which each double current and quadruplex circuit is worked during the busiest period of the year.

t_2 = one quarter of the sum of the times (in hours) during which all other circuits are working.

N = total number of circuits of all types requiring E.M.F.s of over 24^v.

Where the number of single current circuits upon either side of the battery is unequal, provision is, of course, made on the basis of that requiring the larger current.

The capacity (A_1) of the 24^v cells is:—

$$A_1 = \frac{3\,C_1\,t_3}{N_1}$$

where C_1 = the sum of the currents flowing if every line and local circuit upon the more heavily worked side of the 24^v battery is in operation.

t_3 = one quarter of the sum of the time in hours during which each circuit is used during the busiest period of the year.

N_1 = number of circuits operated from the more heavily worked side of the battery.

These formulæ provide a margin of 60%.

PART II.—ALTERATIONS IN THE CIRCUIT CONNECTIONS FOR UNIVERSAL BATTERY WORKING.

The general principles underlying the changes which are made in the connections of the apparatus for universal battery working are of a simple and obvious character. In Part I. of this Chapter it was shown that the sending circuits must be simplified to the general form illustrated in Fig. 373. Where currents in both directions are to be transmitted, the two keys or the two positions of the one key must connect either the positive or the negative earthed battery to the line. Excluding the case of intermediate offices, it will be seen that, having altered the sending portion of the key or keys to fit the new conditions, the same terminal of the set must be connected through to line in every case whether the station is up or down. For a down station this entails the reversal of the battery and the reversal of the direction in which the relay is connected. It will also be obvious that the key or keys must not connect the battery to earth.

Protective resistances are inserted in the line battery leads so that, in the event of faults arising, the resulting current may not exceed ½ ampere; but, in cases where the current is too large, the resistance is suitably increased above the value required for protection so as to reduce the current sent over the circuit to the value actually required. Its function is, then, primarily protective, but it may also when necessary be used to take up the surplus voltage, viz. the difference between the voltage used (24^v, 40^v, 80^v, or 120^v) and that actually necessary.

In the case of intermediate offices the key or keys must be of the same type as in ordinary working, since it is necessary to connect the negative E.M.F. to the up line, whilst the positive E.M.F. is joined to the down line, or *vice versa*. Since the key or keys merely effect a reversal, the same E.M.F. is necessarily connected to both the up and to the down line. Where the resistances of these lines differ widely, artificial resistance is introduced into the shorter line in order to prevent the current sent out attaining too high a value.

These are, then, briefly the general underlying principles which govern the changes necessary, and a careful review of the above generalizations should, after reading the details of the various changes, prove of service in memorizing the general scheme.

USE OF RESISTANCES BETWEEN THE FUSES AND INSTRUMENTS.

Resistance is inserted in the line battery leads to prevent heat coils, now so generally employed owing to the growth of electric tramways, from being operated through line faults and also to avoid the blowing of fuses in the distribution and fuse cases by momentary short-circuits at the instruments. These resistances amount to 2^{ω} per volt of E.M.F. used so that the maximum current due to a dead short-circuit can only be ½ ampere. A 50^{ω} metal-cased resistance coil is placed in each 24^{v}, and an 80^{ω} coil in 40^{v}, lead, whilst a 100^{v} 16 candle-power carbon filament lamp having a resistance of about 300^{ω} when cold is similarly interpolated in the 80^{v} and 120^{v} leads.

The ordinary resistance coil is wound on a boxwood bobbin protected by an ebonite case, whereas the metal-cased resistance coils used in the battery leads are wound on a brass bobbin covered by a brass case. This construction facilitates the radiation of the heat generated by the passage of current through the coil, and whereas the ordinary coil will dissipate the heat generated by 2 watts, the metal-cased coil will dissipate 7 watts, *i. e.* 1·68 calories per second.*

Since the only voltages available are 24^{v}, 40^{v}, 80^{v} and 120^{v}, there are many cases in which the current sent out is too high, and the value of the resistance used in the battery lead is then such as to reduce the current to the normal value. For instance, take a double current circuit consist-

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* The maximum sustained current in amperes for ordinary resistance coils is $\sqrt{\frac{2}{R}}$ and for metal-cased coils $\sqrt{\frac{7}{R}}$ where R is the resistance of the coil—

$$\text{Watts} = EC = C^2R\text{; Calories} = \cdot 24 \text{ Watts} \times \text{Seconds.}$$

ing of the Head Office and one out-station and having a line resistance of 200^{ω}. The circuit would be worked with 24^{v} and its resistance 510^{ω} (50^{ω} coil, two galvanometers 60^{ω}, relay 200^{ω}, line 200^{ω}), thus giving a current of 47 m.a. instead of 10 to 15 m.a. This current is produced by 24^{v} through 2400^{ω} to 1600^{ω}, therefore the resistance to be inserted in each lead to the key is 460^{ω} less than these figures, *i. e.* between 1940^{ω} and 1140^{ω} and as resistance coils from 1000^{ω} to 2000^{ω} are provided in gradations of 250^{ω} the coil chosen would be 1500^{ω}. In this case an ordinary 1500^{ω} resistance coil would replace the metal cased coil. The current could not now exceed 16 m.a. in the event of a dead short-circuit.

In the case of local circuits the battery lead passes through the 900^{ω} sounder to the relay, and therefore no protective resistance is required.

*SINGLE CURRENT WORKING.**

SINGLE CURRENT SOUNDERS.

The internal connections of an up set (Fig. 390) are similar to those described on page 225. The positive voltage is connected through a 1 ampere fuse in the distribution and fuse case via the metal-cased resistance coil *r* to the front stop of the key. The local circuit is taken from the 24^{v} positive or negative, as the case may be, through the sounder to *M* of the relay, *T* of which is earthed at the table.

The down set shown on the left is given the negative voltage so that the current sent out to the up station may be in the marking direction. The connections of the relay are reversed so that a mark may be made by the up station which sends positive to line to mark. The galvanometer connections also are reversed so that marking currents may produce a deflection to the right.

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* The single needle and double plate sounder have practically disappeared from the Post Office, and therefore the alterations required for universal battery working are omitted. They are, however, explained in detail in the earlier editions, and full diagrams are given on plates 36, 38, 39, 40 of *Connections of Telegraphic Apparatus and Circuits, G.P.O.* After consideration of the double current sounder, the alterations can, if required, readily be obtained with the aid of the following notes :—(i) For terminal sets, the right-hand portion of the copper spring of the commutator is cut away and the left front contact screw disconnected and currents sent to line via the up line terminal *A*. (ii) The direction in which the battery leads, the coils or galvanometer, and the relay are connected, is reversed for down sets. (iii) Intermediate sets require no alteration to the internal connections of the commutator.

In the case of an intermediate set, shown in skeleton in Fig. 391, a 6-terminal reversing key is employed and both positive and negative voltages are required. With this key at rest, a positive current coming in on the up line passes through the relay in the direction *U* to *D* and out on to the down line. When the key is depressed the positive voltage is joined to the down and the negative to the up line, and the currents are therefore in the correct direction to actuate the relays at the terminal stations. A second galvanometer is employed in order to indicate currents going out upon both sides.

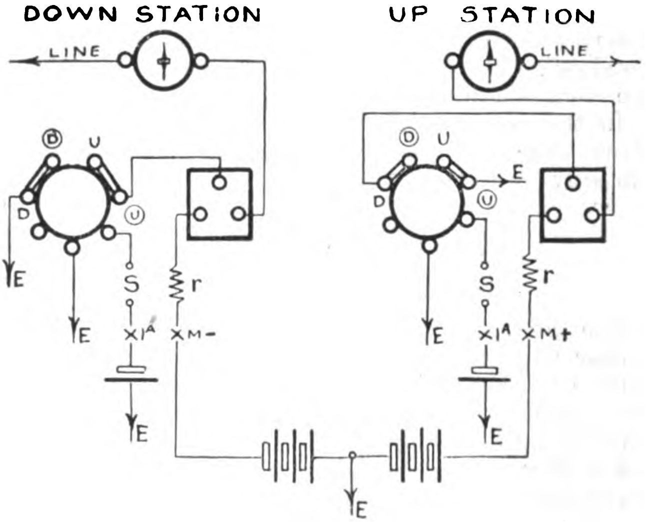

Fig. 390.—Up and down single current sounders.

The currents sent out on the up and down lines when their resistances differ materially are made approximately equal by increasing the resistance of one of the metal-cased resistance coils. For example, a 50^{ω} coil would be used in the negative and a 300^{ω} coil in the positive battery lead if the down line has a resistance of 250^{ω} more than the up line. By placing the resistance in the battery lead the resistance of the circuit from each out station is not increased as would be the case were the resistances levelled up by placing a 250^{ω} coil in the line—a course which would involve an increase in power at the out stations.

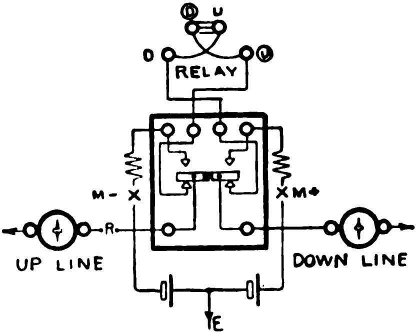

FIG. 391.—Single current sounder intermediate station.

Direct sounder, and direct writer circuits are dealt with upon the same principle.

SINGLE CURRENT DUPLEX.

A 9-terminal 2-position switch replaces the duplex switch shown in Fig. 138, in order that the battery resistance coil may not shunt the plain coil of the relay during simplex working. The coils of the relay and galvanometer are joined in series for duplex working and the right coil of the galvanometer is used at simplex as in the quadruplex.

The full connections of an up set are shown in Fig. 392. For a down set, the negative voltage is joined to the key, the connections on *D* and *U*-circle, on the upper and on the lower terminals of the galvanometer are reversed.

There is a small number of circuits having lines which are entirely underground, where the duplex switch is omitted and the circuits permanently duplexed. The connections are, however, identical with those of the set shown in Fig. 392 when at duplex, but with the switch connections directly made.

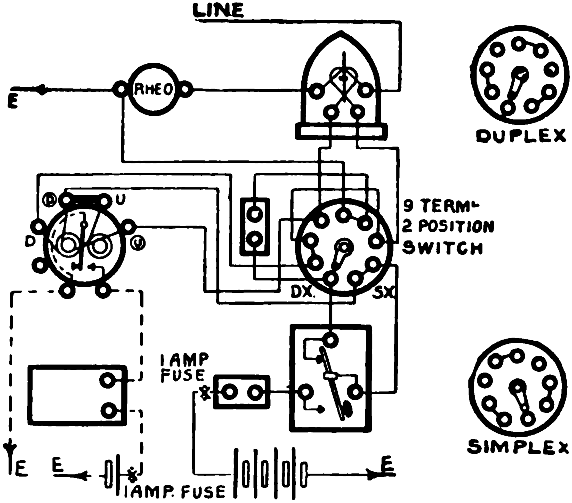

Fig. 392.—Single current sounder duplex.

DOUBLE CURRENT SOUNDER.

Double current working may, in the case of an up station, be effected by disconnecting the front left-hand terminal of the key and joining the positive and negative voltages to *C* and *Z*. For a down station, the galvanometer, relay, and battery connections would have to be reversed, the line joined to the galvanometer and the relay earthed, still leaving the left terminal of the key disconnected.

As double current circuits are very numerous, a special key of simple form has been designed. It is known as the "single current key with switch" (Fig. 393), and consists of a single current key with a two-way switch mounted upon the one base. The front right-hand terminal is connected to the centre of the switch and corresponds to the similar terminal of the ordinary double current key. At receive, the two front terminals are joined across, and therefore the left corresponds to the central terminal of a double current key. *Z* and *C* are, as in every form of key, respectively upon the left and right, whilst *C* is connected to the front stop of the key. The skeleton connections in each position of the key are shown in Fig. 394.

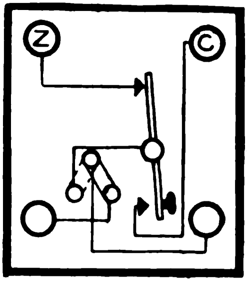

FIG. 393.—Single current key with switch.

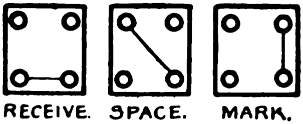

FIG. 394.—Skeleton connections in each position of S.C. key with switch.

Two circuits, the one an up, and the other a down station, are shown connected to a universal battery in Fig. 395. The up set calls for little comment since the connections are as in ordinary double current working, save for the substitution of the 4-terminal key. In the case of the down set the connections of the relay are reversed, as also are those of the galvanometer. The positive and negative voltages are connected to *Z* and *C* respectively whilst the line is joined to the galvanometer. By sketching the arrangement working to an up office it may readily be shown that the alterations straighten the signals at either end, and that the reversal of the galvanometer makes the directions of the deflections the same as for an up set.

For intermediate sets the ordinary double current key is retained, since currents have to be sent out upon both the up and the down line. Where the up and down lines differ greatly in resistance, a suitable resistance coil is inserted between the relay and the left side of the key, as shown in Fig. 396. In this way the resistance of the up is made equal to that of the down line. Where the conditions are reversed, *i. e.* where the down line has the lower resistance, the battery and the relay are each reversed, as also are the positions of the up and down lines.

The balancing resistance is not included in the path of the currents received from the terminal stations, and their respective battery powers are not, therefore, increased when changing from separate to universal battery working. By the aid of Fig. 396, which shows the terminal, as well as the intermediate stations, the conditions stated may readily be verified.

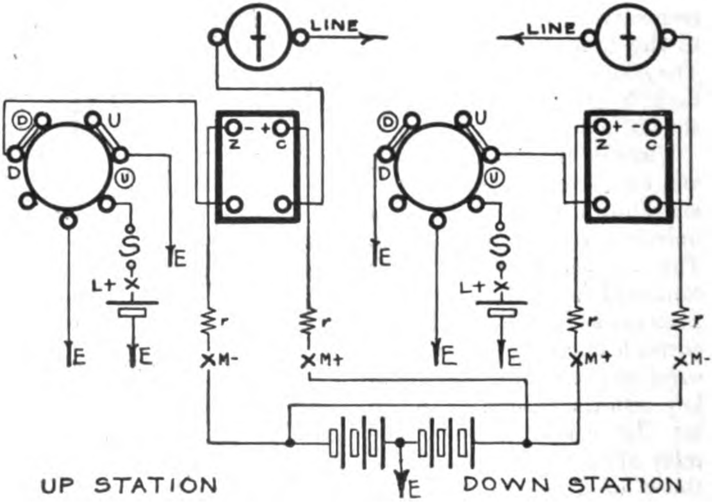

Fig. 395.—Up and down double current sounders.

Double Current Duplex.

The arrangements necessary for duplex working, although somewhat different from those previously considered (see Fig. 148), are by no means complex. A single current key with switch takes the place of the ordinary double current key and the separate coils of the galvanometer are placed in series with those of the relay, since the "double split" cannot be employed. The skeleton connections of a duplex station working to a down station of the ordinary type are shown in Fig. 397.

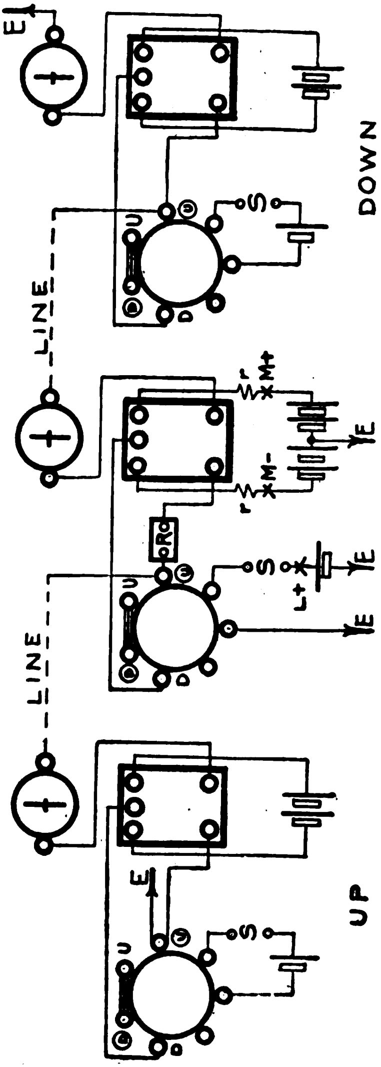

Fig. 396.—Double current sounder intermediate station.

In the normal position, with both keys at rest, the path of the current is from the positive pole of the universal battery to earth, in at the down station galvanometer, through the battery, through the line coil of the relay (*D*-circle to *U*-circle) to line, through the right-hand coil of the home galvanometer, through the relay (plain coil *D* to *U*) back to the battery. The current in this circuit is twice as great as that in each of the compensation circuits, and the preponderating current therefore produces a space at both ends. If both keys are down the current is throughout reversed in direction, and a mark is therefore registered at each end. When one key only is depressed the batteries oppose, and the compensation circuits are left free to produce a space at the end where the key is down, and a mark at the station where it is at rest.

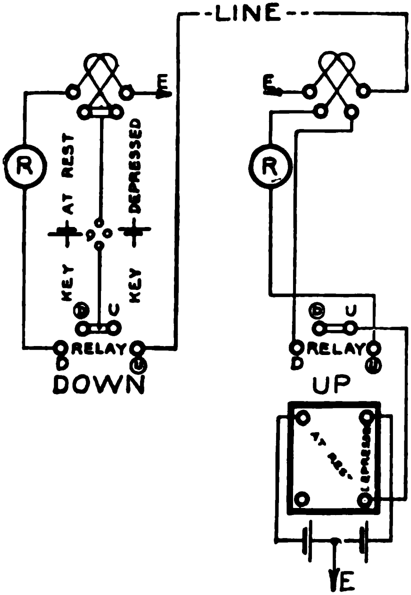

Fig. 397.—Principle of double current duplex working with universal battery.

The single current key produces a disconnection when moving from the normal to the depressed position, or *vice versa*. The condition is of momentary duration only, and no evil effects result. The point was, however, fully considered in relation to ordinary single current working (*vide* page 258), and no further comment should be necessary.

The connections of an up station are shown in Fig. 398. The skeleton duplex connections have already been dealt with (Fig. 397), and it therefore remains to indicate how they are altered for simplex working. When the switch is turned to the simplex position, the split wire is disconnected, the left-hand terminal of the key is connected to *D* of the relay, and the line connected through the right-hand coil of the galvanometer to the front right-hand terminal of the key. The path of a received spacing current is through the line coil of the galvanometer, via the strapped terminals of the duplex switch, through the key, relay, rheostat and left coil of the galvanometer. Since the rheostat is in circuit at simplex, care should be taken to see that no resistance is left in it. The currents sent out pass to line through the right-hand coil of the galvanometer only.

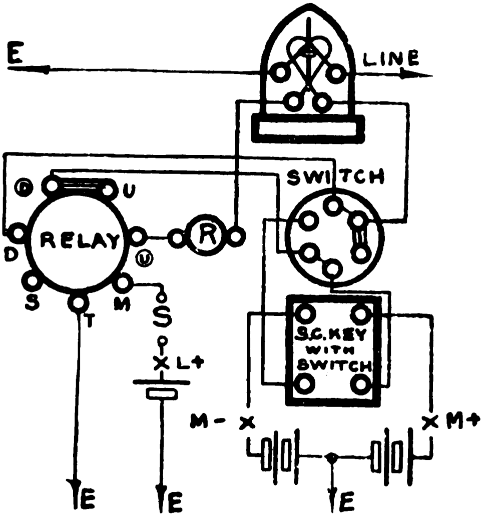

Fig. 398.—Connections of double current sounder duplex.

For simplicity, a rheostat only has been shown (Fig. 398) in the compensation circuit, but where the line is of sufficient length, a condenser, condenser coils, and retardation coils are, of course, added as in ordinary duplex working.

The figure shows the connection for an up station. At a down station (i) *D* and *U*-circle are reversed, (ii) positive and negative voltages are respectively connected to *Z* and *C*, (iii) the wires on the two upper terminals of the galvanometer are reversed, and (iv) the wires on the two lower terminals of the galvanometer are reversed.

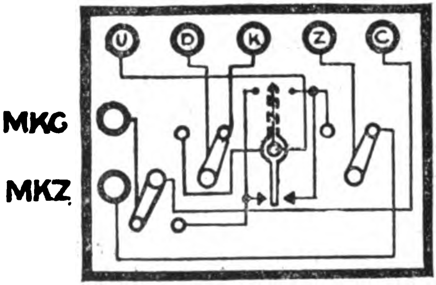

FIG. 399.—Wheatstone transmitter with upper contacts removed.

WHEATSTONE.

It is essential that the transmitter shall not connect either voltage direct to earth, and accordingly the two upper contact points are withdrawn from the reach of the divided lever, as indicated in Fig. 399.

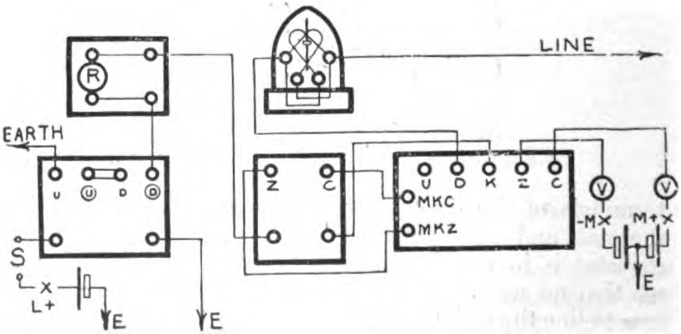

FIG. 400.—Full Wheatstone set for a terminal station.

The connections of a full Wheatstone circuit are shown in Fig. 400, and call for but little comment. With the transmitter running, currents are sent to line from *D*. At rest, the positive and negative voltages are joined to *C* and *Z* of the key, and its currents pass to line through *K* and *D*. The *U* terminal of the transmitter is unconnected. The remaining portions of the circuit are apparent.

For a down station the connections of *D*-circle and *U* and those of the galvanometer are reversed, whilst the battery is reversed at *Z* and *C* of the transmitter.

A lamp is inserted in each battery lead for the reasons given upon pages 355 and 608.

SPECIAL CIRCUITS.

In every large office there is a number of Wheatstone sets which are used only for "special" work, such as race meetings, speeches, and cricket matches; also a number of circuits which only require to work Wheatstone occasionally, or which need it during certain hours of the day, are fitted so that they may be used for special work. All these circuits are fitted with transmitters and receivers, and provision is also made for intermediate working if required. As the sets may be required to work as up or down, and as the shorter line in intermediate working may be either an up or a down line, a reversing switch is added, so that the requisite changes may be made at the instrument. The difference between the resistances of the up and down sides in intermediate working, of course, varies with the lines connected, and therefore the balancing resistance is adjustable—it is, in fact, a set of condenser coils (Fig. 22).

The connections of a special set are shown in Fig. 401. The test-box arrangements are described in Chapter XX., and it will, therefore, only be necessary to remark that the line passes through the line and instrument jacks to the galvanometer, and that the "intermediate return" jack is used for the connection of the second line when working intermediate. This line is always the shorter, or line of lower resistance.

The reversing switch is of the "peg" form, and consists of eight springs corresponding to the eight terminals. The peg also carries eight springs, four upon either side of the ebonite handle which supports them. These springs are connected together, as indicated by the dotted lines in Fig. 402, and therefore reversing the peg connects the four top terminals horizontally and the lower four vertically. The four upper terminals control the reversal of the receiver, and the lower set the reversal of the battery.

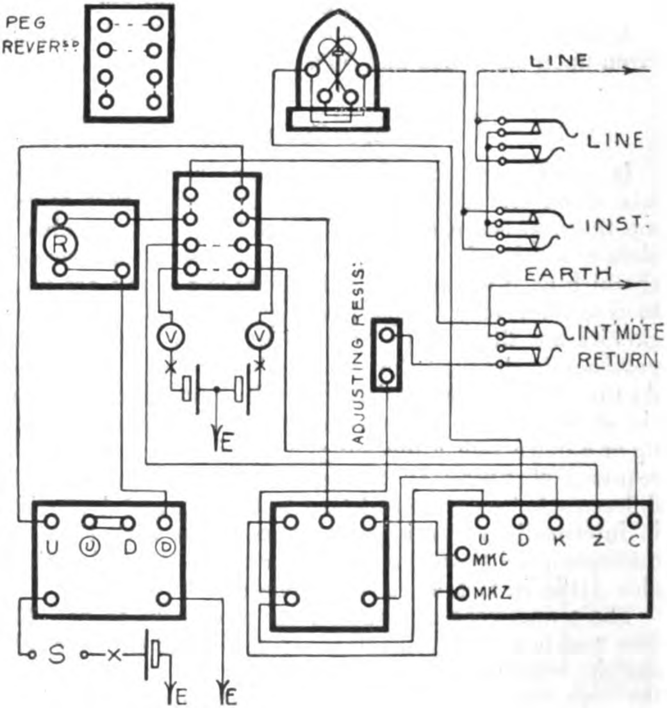

Fig. 401.—Wheatstone special set for up, down, or intermediate Wheatstone working. (Peg switch connections for working as a down station to the long lines.)

When used as a terminal station there is no line connected to the intermediate return jack, and consequently *U* of the transmitter and the left terminal of the double current key are disconnected. The arrangement is then identical with that of Fig. 400, save that the double current key does duty for the single current key with switch. The reversing switch is used to alter the set to up or down as may be required when any new circuit is connected to it.

When the set is required for intermediate working the shorter line is connected to the "intermediate return" jack by means of solid plugs and cords. The insertion of the plug cuts away the earth connection, and bunches the wires from the adjusting resistance and the receiver (via the switch) to the short line. Suitable resistance is then inserted in the adjusting resistance box and the signals straightened, if reversed, by reversing the peg switch. In the latest arrangement a second galvanometer is placed in series with the adjusting resistance (compare Fig. 402).

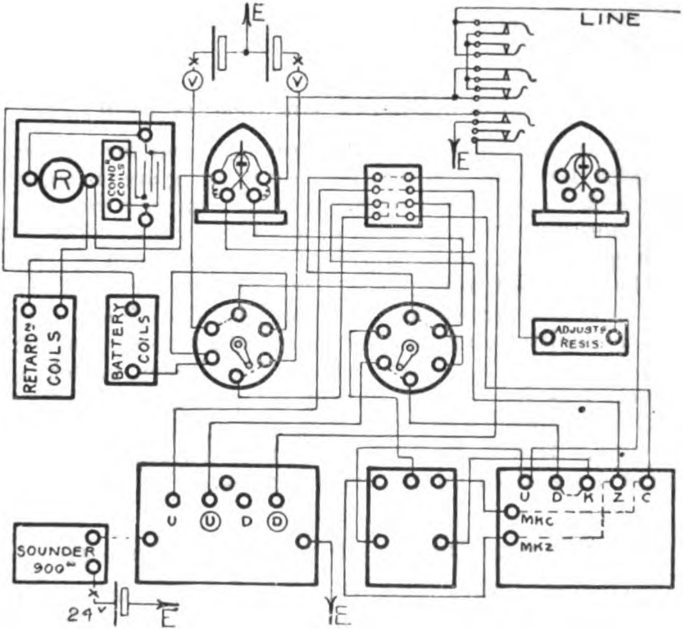

FIG. 402.—Wheatstone special set for duplex or simplex terminal or intermediate working. (Peg switch connections for working as an up station to the long line.)

The received currents pass from the long line, through the galvanometer, through *D* and *K*, through the receiver and shunted condenser out on to the short line. The adjusting resistance does not form part of the received circuit. Transmitter currents pass out between *U* and *D* of the transmitter, and the adjusting resistance is included in the circuit of the shorter line. The key currents pass through *D* and *K* of the transmitter and the adjusting resistance.

WHEATSTONE DUPLEX FOR SPECIAL SETS.

The connections of a special set arranged for duplex, simplex, terminal, and intermediate working are shown in Fig. 402. The battery switch normally connects the positive and negative voltages to the peg switch, which is arranged as in simplex working, *i. e.* it serves to reverse the battery and to reverse the relay terminals. The battery switch in the "resistance" position joins both *Z* and *C* of the transmitter through the battery coils, one side of which is permanently earth-connected. The duplex switch is arranged as in Fig. 398, and by comparing it with Fig. 402 there should be no difficulty in tracing the arrangement through. It will also be observed that a second galvanometer is added for intermediate working.

WHEATSTONE DUPLEX (DIFFERENTIAL SYSTEM).

In this case the transmitter is added precisely as in Fig. 400, and *D* of the transmitter is joined to the lower terminal of the duplex switch. The receiver takes the place of the relay shown in Fig. 398, and the battery switch is arranged as in the "special set" duplex (Fig. 402). A reversing switch is not provided, and the single current key with switch is, of course, used in place of the double current key, and the upper contacts of the divided lever in the transmitter are withdrawn. The working out of the full connections should now prove quite simple.*

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* *Connections of Telegraphic Apparatus and Circuits*, *G.P.O.*, plate 62.

WHEATSTONE DUPLEX (BRIDGE SYSTEM).

The positive and negative voltages are joined to a 6-terminal 2-position switch just as in the special set duplex, and the single current key with switch and the transmitter are connected as in Fig. 400. The top left-hand terminal of the 9-terminal duplex switch is taken to the left terminal of the single current key and the *U* terminal of the transmitter is left disconnected. The remainder of the connections are as in Fig. 225.*

QUADRUPLEX.

The only feature which is special to the universal battery worked quadruplex is the arrangement of the sending circuit. A 6-terminal reversing key and a double current key with adjustable contacts are used as the *B* and *A* keys respectively and are connected as shown in Fig. 403. The negative and positive low voltages are connected through fuses and 300ω metal-cased resistance coils to the lower springs, and the positive and negative higher voltages through fuses and lamps to the upper springs, of the *B* key.

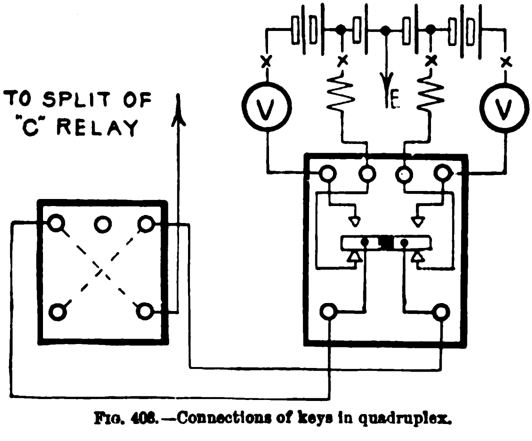

FIG. 403.—Connections of keys in quadruplex.

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* *Connections of Telegraphic Apparatus and Circuits*, *G.P.O.*, plate 64.

It will thus be recognized that the *B* key when at rest connects the negative and positive low voltages and when depressed the negative and positive high voltages through

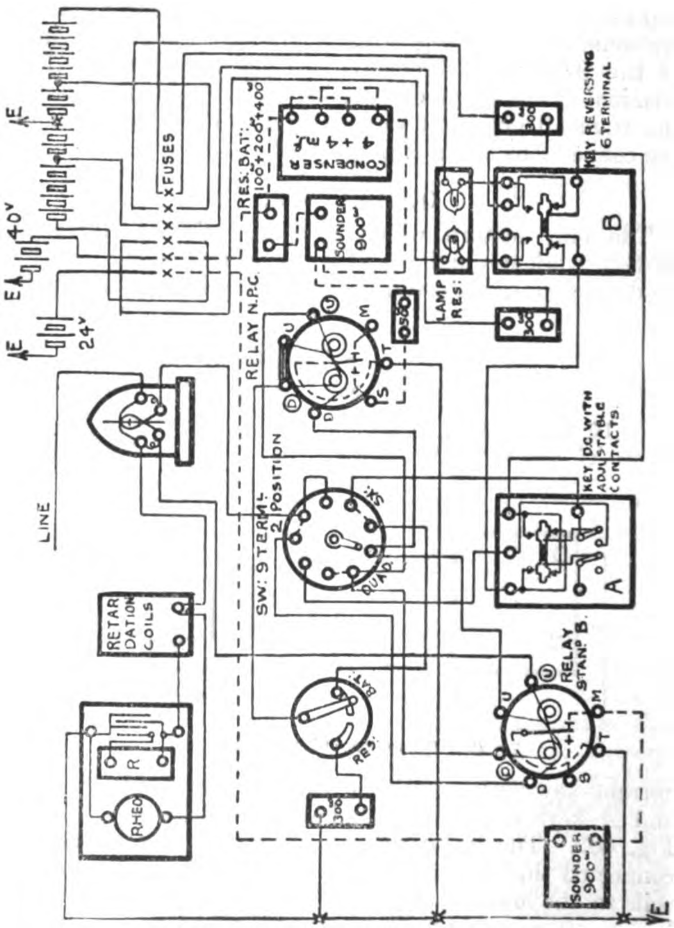

FIG. 404.—Quadruplex up station (universal battery system).

to *Z* and *C* of the *A* key, which according to its position selects the negative or positive voltage.

If the connections of the keys in Fig. 160 are modified to those of Fig. 403, the connections of the universal battery worked quadruplex, shown in full in Fig. 404, are obtained.

The resistances of the lamps, metal-cased resistance coils, and the earthing resistance in connection with the two-way switch are each approximately 300ω.

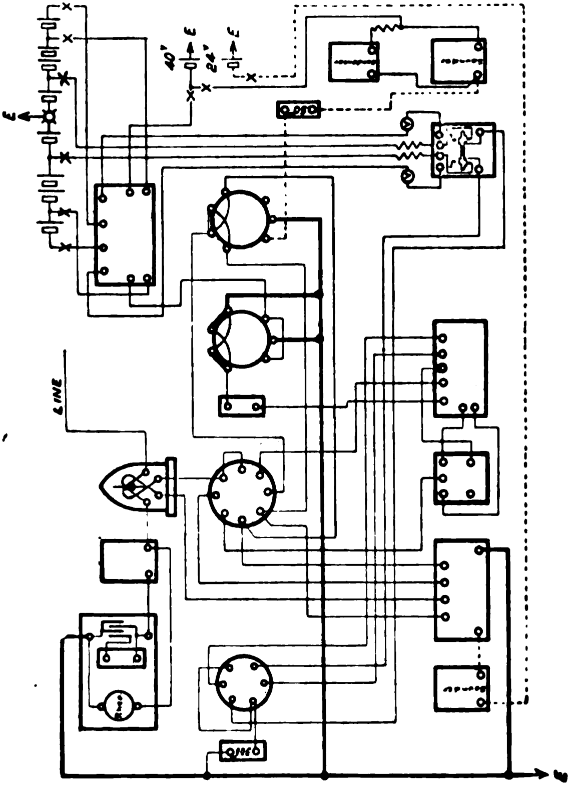

FIG. 405.—Connections of quadruplex with Wheatstone on the *A* side.

If the apparatus is required to work as a down station the wires on *D* and *U*-circle of the *A* side relay, those upon the upper and those upon the lower terminals of the galvanometer and the battery wires on the *A* key must each be reversed.

The full connections of a quadruplex with Wheatstone on the *A* side and incrementing voltages is shown in Fig. 405. The function of the incrementing voltages is as in the primary battery worked quadruplex, but as both negative and positive voltages are supplied to the *B* key an automatic switch (*vide* page 636) takes the place of the relaying sounder shown in Fig. 164, and the earthed neutral relay is joined through a 3000ω resistance coil to *U* of the transmitter. When the transmitter is running, the lower half of the divided lever sends currents through the neutral relay the local circuit of which closes the automatic switch, thus increasing the voltage.

This arrangement is not necessary in every case, and the ordinary connections for Wheatstone on the *A* side are obtained by eliminating the incrementing devices.

The connections of the transmitter and of the receiver which replaces the *A* relay are sufficiently obvious.*

At a down office the wires on *U* and *D*-circle of the receiver, the wires on the upper and on the lower terminals of the galvanometer, and the wires on the front of the *B* key are each reversed.

The use of the electromagnetic switch may be avoided by connecting the full voltage to *Z* and *C* of the transmitter and interpolating an opposing primary battery between *M K Z* and *Z*, and between *M K Z* and *C*, of the key, but this course is open to serious objection in a large office. The use of dry cells placed in or beneath instrument tables, with the necessity for frequent tests to ascertain their condition, cannot be recommended. There is yet another plan (adopted by P. Mulligan in the C.T.O.) which is simpler than the arrangements shown in Fig. 405, and avoids the disadvantages of detached primary cells. It consists in connecting the full voltage, via the *B* key (with the usual 300ω resistance lamps in each lead), to *Z* and *C* of the transmitter, and in connecting this full voltage also to *Z* and *C* of the key, but interpolating in each lead an amount of resistance sufficient to take up the surplus voltage, the connections *MKZ* and *MKC* of the transmitter being left disconnected. The value of the resistance is determined for each particular circuit, and should be such that there is no appreciable difference in the duplex balance at the distant station between key and Wheatstone working.

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* *Connections of Telegraphic Apparatus and Circuits, G.P.O.*, plate 72.

Test Box Speaking Set.

The only feature of the arrangement which is not common to an ordinary double current set with facilities for intermediate working is that any of the voltages from 24ᵛ to 120ᵛ may be connected to it according to the positions of the two U-links (Fig. 406).

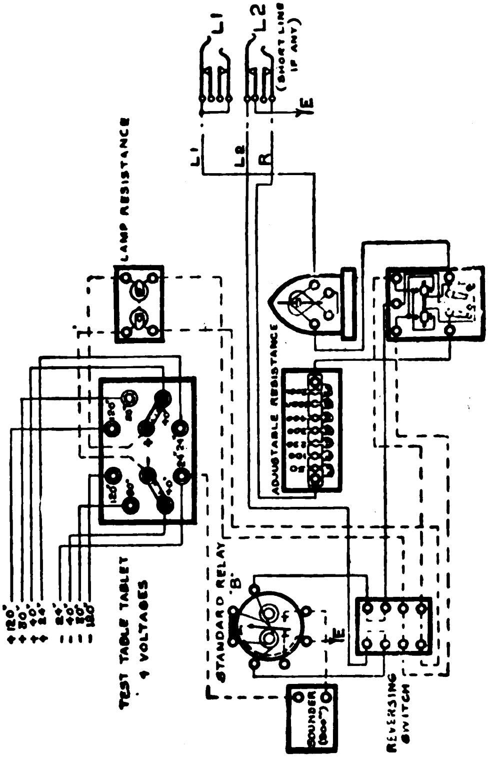

Fig. 406.—Connections of test box speaking set.

CHAPTER XIX

REPEATERS.

Working Speed of a Circuit.

THE time taken for the current in any given circuit to rise to any specified percentage of its maximum value is directly proportional to the product of the total capacity and total resistance of the line. This value is obviously related to the working speed of the circuit, and, by collecting the results of a very large number of experiments, extending over several years, the following empirical formulæ have been obtained by A. Eden for circuits worked with shunted condensers at the receiving end and applicable to British lines which usually have had from 3% to 8% of underground associated with the aërial work:—

$$\text{Speed in words per minute} = \frac{A}{KR}$$

A = 10 for aërial iron wire line
= 12 „ „ copper „
= 15 „ subterranean, or submarine, G.P. covered wire.
K = capacity in farads, R = resistance in ohms.

If a signalling condenser, equal in capacity to the discharge value of the line under working conditions, is attached at the sending end shunted by a resistance equal to the total conductor resistance of the line, the value of A for simplex working becomes 18.

All the formulæ assume that a shunted condenser is used at the receiving end, and that the battery power is upon the basis of that required to furnish 8 m.a., with a minimum E.M.F. of 100 volts.[*] It also assumes that the battery resistance does not exceed 3^{ω} per volt of E.M.F.

The working speed obtainable from the formulæ is, of course, subject to the limit of the speed at which the apparatus can be worked, and this does not exceed 600, and, in practice, is rarely above 400 words per minute.

A rapidly alternating current does not evenly distribute itself throughout the cross section of the conductor through which it is flowing. The current is densest upon the outer parts and is least dense in the centre. Owing to the fact that iron is a magnetic material, this "skin effect" is more marked with iron than with copper conductors. Taking an iron and a copper wire of equal length and equal resistance to a steady current it would be found that the iron wire offered a higher resistance than the copper one to an alternating current. It is to this fact that the lower speed obtainable with an iron wire is to be attributed and not to the fact that the iron wire possesses a higher self-inductance than the copper one. The increased self-inductance would be distinctly beneficial and not detrimental (see page 631).

BATTERY RESISTANCE.

The internal resistance of the battery employed upon a Wheatstone circuit has an important effect upon the speed of working. If the resistance is below 1^{ω} per volt of E.M.F. used, the transmitter will very quickly be placed out of action by excessive sparking, whilst a value in excess of $2{\cdot}5^{\omega}$ per volt will reduce the working speed. Consideration will show that the action of resistance in the sending circuit will be in every way similar to the action of the retardation and condenser coils used to slow down the rate at which the condensers in the compensation circuit of an ordinary duplex are charged. The *maximum* value of the current in the *sending* circuit of a Wheatstone circuit is frequently well over 250 m.a., whereas the received current

[*] Lines of high capacity require very high receiving condenser shunts to give the speeds indicated from the formulæ.

may not exceed 10 m.a. It is for this reason that heat coils having a striking-point of 500 m.a. are invariably used upon such circuits in preference to those having a striking-point of 250 m.a. (see page 704).

KELVIN'S LAW AND ARRIVAL CURVE.

Lord Kelvin's name will for ever be associated with his classical solution of the mathematical problem of the propagation of currents in telegraph cables.* The relation between the E.M.F. applied to a cable and the value of the current at each instant at the receiving end is complex, but many important applications of the law can be stated in simple form.

When an E.M.F. is applied to a cable having a capacity of K farads and R ohms resistance the current received is zero until an interval equal to ·023 times the KR in seconds has elapsed. After the lapse of this interval, termed *the silent interval,* the current rises gradually until it reaches full strength. At time equal to four times the silent interval the current has reached nearly half, and after the lapse of ten times this interval it is at full strength.

In the case of Atlantic cables having KR of from 2·4 to 8, the maximum value of the current is never even

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* The expression for the current received at time t after the application of an E.M.F. of E volts to a circuit having a resistance of $R\omega$ and a capacity of K farads found by Lord Kelvin is:—

$$C = \frac{E}{R}\ 2\left\{\tfrac{1}{2} - \theta + \theta^{4} - \theta^{9} + \theta^{16} - \theta^{25} + \ .\ .\ .\ .\right\} \text{ (i)}$$

where $\theta = \epsilon^{-\frac{\pi^2 t}{KR}}$

A first approximation is $C = \frac{E}{R}\left(1 - 2\epsilon^{-\frac{\pi^2 t}{KR}}\right)$

At time $t = \frac{KR}{\pi^2}$ *i.e.* $\frac{KR}{9 \cdot 87}$ $C = \frac{E}{R}\left(\frac{2\epsilon - 1}{2\epsilon}\right) = \cdot 81606\ \frac{E}{R}$ or very roughly $C = \frac{4}{5}$ of $\frac{E}{R}$ after time in seconds equal to ·1 KR. C is zero for all values of t up to ·023 KR second. At t = ·23 KR second it is at full strength.

approached, but on the German cables which are the longest worked by the Post Office, the current attains half its full value in rather less than $\frac{1}{50}$ and its full value in $\frac{1}{20}$ second. On any circuit which admits of a Wheatstone speed of 400 words per minute, the full value flows after the lapse of ·007 second, whilst the length of a dot current is rather less than ·02 second. It will therefore be recognized that in the case of all circuits within the Kingdom the current attains its full ohm's law value.

Every telegraph receiving instrument requires a certain minimum current for a certain length of time in order to actuate it. The time taken for the current to attain this value, and hence the speed of working, is inversely proportional to the *KR* of the circuit. Signals cannot succeed each other at intervals more frequent than the time taken to affect the instrument.

The effect of low insulation is to reduce the value of the current received due to a given E.M.F., but if the E.M.F. be raised to produce the same value of received current the working speed is increased because the leakage reduces the static charge on the cable. The effect of the inductance of the cable itself is to increase the speed, but the rate or frequency of the alterations is too slow for either inductance or leakage to produce any very material benefit. In the case of telephone circuits the frequency is very much higher and the efficiency of a subterranean circuit can be increased more than threefold by inserting distributed inductance in the circuit.

The application of a large number of "inductive leaks" evenly distributed throughout the length of a long submarine cable may possibly in the future be put to a practical test, but so far as telegraph circuits within the Kingdom are concerned experience has discovered no authentic case in which the working speed has been increased owing to a small or large fall in the general insulation of the circuit. Upon the other hand, it is found that when the total insulation is less than the conductor resistance the speed is materially reduced.

The capacities of the various types of aërial and underground wire are as given in the following table:—

CAPACITY AND RESISTANCE OF VARIOUS TYPES OF LINE. (A. EDEN.)

Type of line.	Type of wire.	Gauge.	Capacity in m.f.s per mile.	Resistance per mile in ohms.
Aërial	Copper	100 lb.	·0144	8·7873
”	”	150 lb.	·0147	5·8582
”	”	200 lb.	·015	4·3936
”	”	300 lb.	·0153	2·9291
”	”	400 lb.	·0156	2·1968
”	”	600 lb.	·0158	1·4645
”	”	800 lb.	·016	1·0984
”	Iron	400 lb.	·0157	13·32
”	”	450 lb.	·016	11·84
G.P. Underground	Copper	40 lb.	·3	21·956
Screened cable	Copper	40 lb.	·125	21·956

Note on the above Table—The table assumes average distribution of trees, and twelve wires upon the poles at an average height of thirty feet above the ground. Where there is only one circuit upon the poles the value of the capacity given in the table should be reduced by 28%. The capacity of an open or aërial metallic circuit is five-eighths of that of a single wire circuit of the same type of wire. With underground wires it is one-half.

Example.—What is the working speed of a circuit consisting of 200 miles of 150 lb. aërial copper wire and 50 miles of G.P. underground ?

Note.—The *KR* of a mixed circuit is the product of the total resistance and total capacity—not the sum of the *KR*s of the separate sections. Also, where the circuit is a mixed one, *i. e.* partly open and partly covered, the lower speed constant is taken.

Res. of 200 miles of 150 lb. copper	=	1171·
” ” 50 ” ” G.P.	=	1098·
Total resistance	=	2269·
Capacity of 200 miles of 150 lb. copper	=	2·94 m.f.
” ” 50 ” ” G.P.	=	15· m.f.
Total capacity	=	17·94 m.f.

$$\because KR \text{ of circuit} = 2269 \times \cdot000{,}017{,}94$$

$$\text{Speed of working} = \frac{12{,}000{,}000}{2269 \times 17\cdot94}$$

$$= 295 \text{ words per minute.}$$

A working speed of 400 words per minute is obtainable through the following lengths of line of each class:—

150 lb. copper wire aërial line . .	590 miles.
100 lb. " " " " . .	487 "
450 lb. iron " " " . .	363 "
400 lb. " " " " . .	291 "
G.P. underground line . . .	83 "
Screened paper cable 40 lb. . .	128 "

Since the length of the circuit enters into both the total capacity and the total resistance, it will be obvious that, with any given type of line, the speed of working is inversely proportional to the square of the length of the circuit. For instance, the *KR* of 100 miles of G.P. underground is ·06815 and that of 50 miles ·0170375, hence the working speed of the latter circuit is four times as great as that of the former.*

The same *KR* underground admits of a *greater* proportionate Wheatstone speed, the exact value depending upon the dielectric. Generally speaking india-rubber gives a lower speed than gutta-percha-covered wires for the same *KR*, and the lower the speed the greater is the difference, electrification being a factor. Again, paper cables give a lower value than gutta-percha, but the screened conductor types give higher speed than even twisted metallic circuits in a paper cable.

It is also found that duplex circuits, whether bridge or differential, give a speed which is slightly less than two-thirds of the highest speed obtainable under the best conditions for simplex circuits.*

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* With underground lines the speed of working of a metallic circuit is the same as that of a single wire between the two stations, the reason being that whilst the resistance of the circuit is doubled its capacity is halved by the addition of the second wire. With aërial lines the speed of a metallic telegraphic circuit on the same poles would be less than that of the single wire, but if the component wires of the loop were divided by a considerable distance the speed on the loop would be the same as on a single wire—as in the case of underground wires.

Hughes' working is equivalent to Wheatstone at 40 words per minute, hence it may be worked at full speed when the *KR* does not exceed ·3.

THEORY OF REPEATER.

Repeaters are employed to increase the working speed of a telegraph circuit. If the speed upon a circuit, wholly of underground or wholly aërial line, is 100 words per minute, then the speed obtainable upon either half of the circuit, when divided in the centre, is not twice but 2^2 times 100, *i. e.* 400, words per minute. Where the circuit consists of short sections of underground, a long open line, and then a section of submarine cable (such as that which connects England and Ireland), a repeater is introduced as near to the cable as possible. This has the effect of dividing the line into two sections, the working speed of either of which is considerably more than that of the whole circuit. The repeater serves to receive and retransmit the signals, therefore the speed of working is that of the section of highest *KR*. With Wheatstone circuits it is not usual to introduce more than two repeaters, save in very exceptional circumstances.

From what has been said it will be seen that the ideal position for a repeater is the centre of the *KR* of the circuit. Where more than one repeater is employed, they should be placed so as to divide the circuit into lengths of approximately equal *KR*.

PRINCIPLE OF SIMPLEX REPEATER.

The general principle of a simplex repeater is illustrated in Figs. 407 and 408. The former figure indicates the arrangement required to enable an up to signal to a down station, whilst the second figure shows a down sending to an up station.

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* On G.P. cables the speeds are $\frac{2}{3}$ of $\frac{15}{KR}$ for differential but $\frac{2}{3}$ of $\frac{18}{KR}$ for bridge because of the addition of signalling condensers.

The up line is joined through a relay to earth, and the tongue of this relay is connected to the down line, *S* and *M* being joined to a divided battery. The tongue of the relay is maintained against *S* by the spacing current from the up station, and a negative current from the left half of the battery therefore passes to the down station. When the up station depresses his key the tongue of the relay moves over to *M*, so transmitting a positive current to the down station which produces a mark at the down station.

In Fig. 408 the down line is terminated through a relay and the up line connected to *T*. It will be observed that the down line is joined to the down side of the relay and that the battery connections are reversed to those of the previous figure. A down station with the key depressed sends out a negative current to line. This current causes the relay to mark and so to transmit a negative current to the up station.

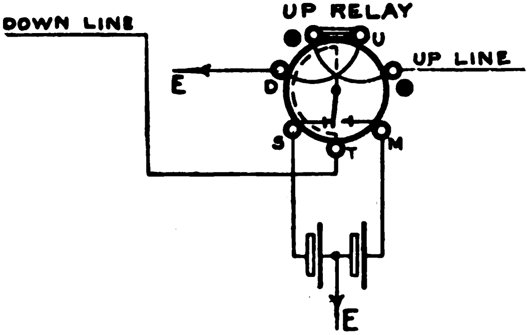

FIG. 407.—Principle of simplex repeater. Up-station sending.

In practice it is necessary to arrange that the terminal stations may work together in either direction. Since the relays are of the ordinary Post Office pattern, it will be seen that (Fig. 407) even where there is no current passing through the up relay from the up line, there will still be a current upon the down line, its direction being either "spacing" or "marking" according to whether the relay has a spacing or a marking bias, or, if the relay be of neutral adjustment, whether the tongue was left on the spacing or marking side by the current last sent through the relay. Similar remarks apply with equal force to the down side (Fig. 408). It is therefore necessary to provide an automatic device which will establish the conditions shown in Fig. 407 when the up station turns his switch to "send," and those of Fig. 408 when the down station's switch is turned. This requirement is met by the use of

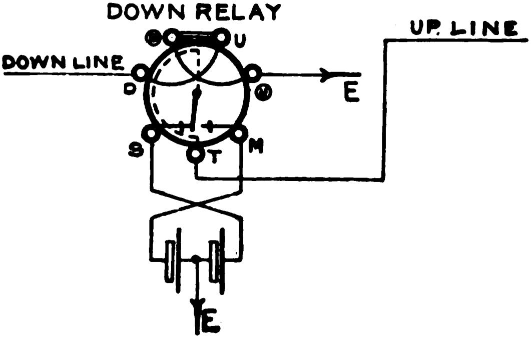

FIG. 408.—Principle of simplex repeater. Down-station sending.

two automatic switches controlled by two neutral relays, which are respectively inserted in the up and down lines, in series with the transmitting relays.

AUTOMATIC SWITCH.

The appearance of the electromagnetic switch or, as it is generally termed, the automatic switch is shown by Fig. 409 whilst its connections are apparent from Fig. 410. It consists of an electromagnet with two armatures, each of which plays between two contact points. When energized, the armatures are attracted, and the levers make contact with the inner stops. The coils are shunted by a non-inductive resistance equal in value to the resistance of the coils. This shunt renders the action of the switch very sluggish—a condition which will be shown to be necessary.

If the current through the coils is momentarily stopped and then re-established the armatures will not break their connections, since the E.M.F., due to the self-induction of the coils, produces a current through the coils and shunt. As the resistance of the shunt is equal to that of the coils the best conditions for the production of a prolonged effect

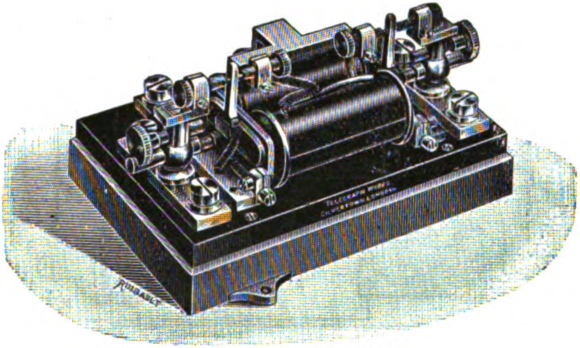

FIG. 409.—Automatic switch.

have been provided. For secondary batteries the coils and shunt are each 1000^{ω} giving a joint resistance of 500^{ω}, and the local voltage is 24.

SIMPLEX REPEATER.

A galvanometer of the differential pattern, with its coils in parallel, is included in each line. In order to provide for communications between the repeater and terminal stations each line passes through the two lower terminals of a single current key with switch, the battery power being obtained by teeing the main batteries upon either side to the *Z* and *C* terminals of the keys.

In the sketch of the connections (Fig. 410) it will be observed that a shunted condenser is placed in series with the two relays upon either side of the repeater. Its function is, as in ordinary Wheatstone working, to hasten the formation and to prevent prolongation of the signals.

A Wheatstone receiver, with a sounder and battery connected to the local, together with an adjustable resistance and shunted condenser device, is provided for observing the signals sent out by the transmitting relays.

It will be seen that the local circuit through the auto-switch is normally disconnected, owing to the central position of the relay tongue, but it is completed when the tongue moves over to either *S* or *M*. If now a series of signals pass through the neutral relay, the tongue will move from side to side in accordance with them. Since the automatic switch has been made sluggish in action by the addition of the shunt, the momentary disconnections which take place whilst the tongue is travelling from *S* to *M*, or *vice versa*, are not of sufficient duration for the armatures to be released. Hence, the automatic switch remains closed so long as currents are passing through the auto-relay.

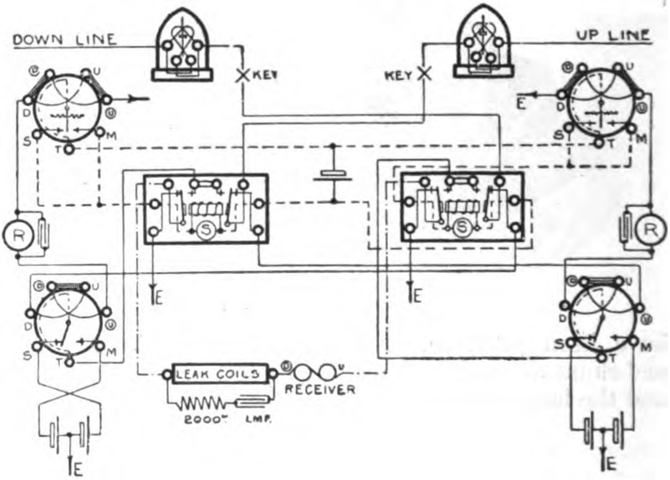

FIG. 410.—Skeleton connections of fast-speed simplex repeater.

The relays, galvanometer, key, automatic switch and shunted condenser, are termed "Up" or "Down" according to whether they are in connection with the up or down lines. The "Up" battery sends currents to the "Down" station, and the "Down" battery to the "Up" station.

The neutral relays are invariably termed "auto" relays in contradistinction to the "transmitting" relays.

PATH OF CURRENT.

When the down station turns his switch a positive current passes along the line to the repeater station, where it passes through the down galvanometer, through the back stop of the up auto, and thence through the down transmitting relay, shunted condenser and down auto-relay to earth. The down auto-relay closes the auto-switch, which connects *T* of the down transmitting relay to the up line. As the current from the down station passes through the relays in the direction *D* to *U* a positive current is sent out through the contacts of the down auto-switch and through the up galvanometer to the up line. A series of signals causes both the down relay tongues to move in accordance with those signals, and, as the momentary disconnection of the auto local circuit does not release the armatures, the signals are accurately transmitted to the up station.

If the down station turns his switch to receive and the up station commences to send, the latter's current passes through the up galvanometer and up relays to earth. The local circuit of the up auto is closed and the up transmitting relay consequently repeats the signals received to the down station.

Inspection of the figure will show that the receiver and leak coils are connected to the up or down line according to whether the repeated signals are being sent out on the up or the down line. The receiver, therefore, serves for observing the character and condition of the marks leaving the repeater station. The adjustable resistance coils in series with the receiver have a total resistance of 20,000$^\omega$, and by this means the current through the leak circuit may be regulated. The resistance of the leak circuit has but little effect upon the value of the current received at the terminal stations. Upon a circuit of 5000$^\omega$ resistance with a battery resistance of 500$^\omega$ the current received is reduced by less than 6% when the leak circuit resistance is reduced from 20,000$^\omega$ to 5000$^\omega$.

A 1 m.f. condenser is placed in series with a 2000^{ω} resistance coil and the combination joined across the terminals of the leak coils, in order to balance the self-inductance of the receiver, and so reduce the tendency to sparking at the contacts of the transmitting relays.

On all fast-speed repeaters now a galvanometer is inserted in series with the receiver in the leak circuit. The galvanometer gives a ready means of determining the neutrality of the repeated signals, and any bias detected can then be eliminated by suitably turning the adjusting screw of the transmitting relay.

DUPLEX REPEATER.

The neutral relays and auto-switches are not needed in duplex working, and therefore the principle and the skeleton connections are simpler than those of the simplex repeater. The tongues of the up and down transmitting relays are respectively connected to the splits of the down and up relays. The compensation circuits are arranged as in ordinary duplex working, and the condensers, rheostat, retardation and condenser coils are denoted by "*R*" in the conventional diagram given in Fig. 411.

At the up and down offices the skeleton connections, when the keys are at rest, are given in order to correlate the various parts of the complete circuit. It is assumed that all four compensation circuits have been balanced as in ordinary duplex working. It will be seen from Fig. 411 that the arrangement of the connections is practically that of two duplex circuits. The up side transmitting relay acts as if it were the key working to the down office and the down transmitting relay controlling the currents sent to the up office. The theory of duplex working has been very fully dealt with in Chapter VIII, and the possible combinations are similar. If, for instance, the up office key is depressed, the tongue of the up transmitting relay moves over to *M*. This reversal causes the up battery to oppose that at the down office and a mark is made at the down office by the compensation circuit passing from *U* to *D*. In Fig. 411 both transmitting relays are responding to spacing currents from the up and down offices. The important point to be observed is

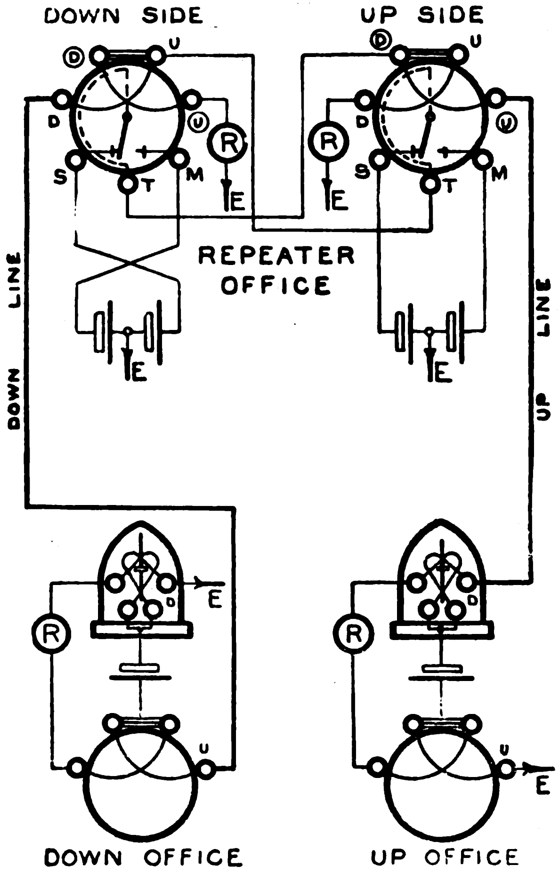

Fig. 411.—Skeleton connections of duplex repeater showing terminal stations with their keys at rest.

that the key at the up office determines the position of the tongue of the up transmitting relay, whilst the down key controls the tongue of the down relay.

The duplex and single switch is of the 8-bar type, and is equivalent to eight two-way switches operated by a single lever or handle. Its functions in changing from simplex to duplex are as follows:—

1. To disconnect the neutral relays
2. To place the galvanometer coils in series with the relay as in Fig. 397.
3. To tee the leak receiver and leak relay to the *T* terminals of the transmitting relays.
4. To place the keys in series with the split wires for balancing and speaking purposes.

In repeaters of the latest type the costly 8-bar switch is replaced by a small and cheap equivalent. The key* is of telephonic type, and consists of 24 springs arranged in four groups of three on each side of the lever. With the key lever in the central position, the centre spring of each group (corresponding to the lever of a two-way switch) of three is in contact with its inner spring. Movement of the key forces each centre spring of each of the four groups away from its inner, to make contact with its outer, spring. Movement of the key in the opposite direction moves the centre springs of the other four groups into contact with their outer springs.

Two battery resistance coils and 6-terminal 2-position switches are provided, as in Wheatstone duplex sets, for balancing purposes. The rheostat, condenser, and its timing resistances upon each side are used as the shunted or reading condenser in simplex working. Two sets of leak coils placed in a single box are used in conjunction with the leak relay and receiver, and each is supplemented by the usual leak condenser, etc., as shown in Fig. 410.

A view of a duplex repeater is given in Fig. 412.

THE LEAK CIRCUIT.

It is essential that the repeater station shall be able to observe the condition of the marks sent out upon either side, so that either office shall always be able to gain the attention

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* *P.O.E.E. Journal*, Vol. VI. p. 69.

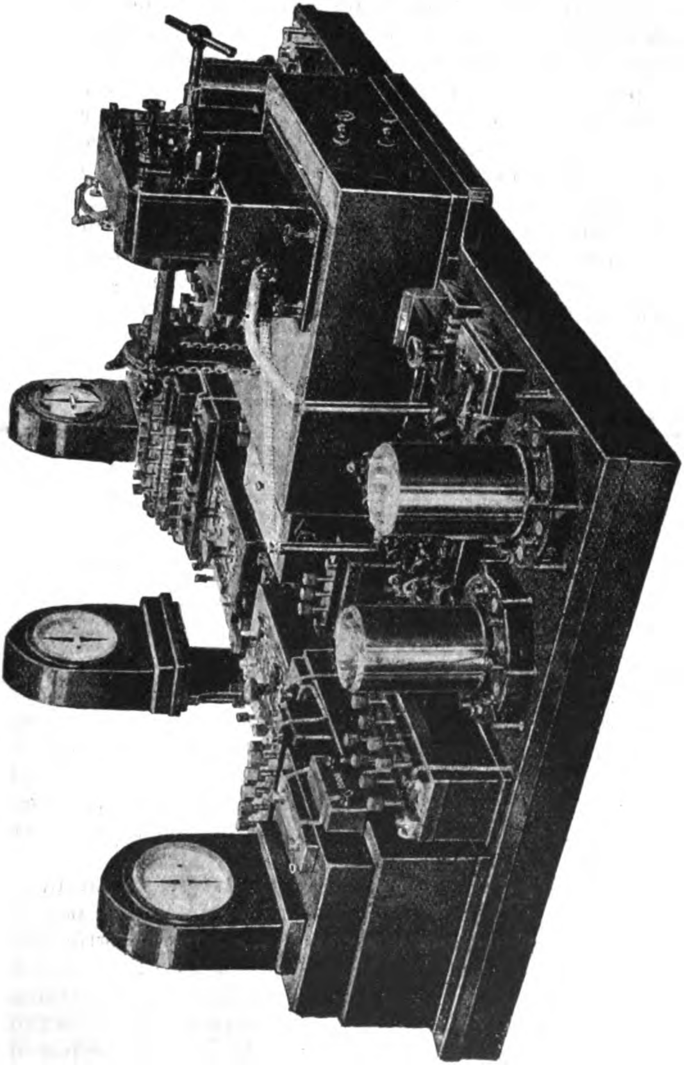

Fig. 419.—View of a duplex repeater.

of the relay clerk. This is provided for by means of the leak switch, which connects the leak receiver and leak relay to the up and down transmitting relays in accordance with the position of the peg. In this way, the receiver may be used to observe the marks sent out upon either side, whilst the two sounders, attached to the leak receiver and relay, serve to indicate calls. In simplex working, either the receiver or the relay may be joined up as in Fig. 410.

The switch consists of fourteen mounted springs (marked 1 to 14 in Fig. 413) and a peg bearing four springs upon either side. The peg may be inserted either vertically between contacts 7 to 14 or horizontally between contacts 1 to 6. The two sides of the peg are marked "receiver" and "relay" respectively, and the switch is so joined up that the engraving upon the peg denotes the sides to which the receiver and relay are connected when the peg is placed vertically. When in the horizontal position, the engraving upon the front side of the peg indicates whether the receiver or relay is in circuit.

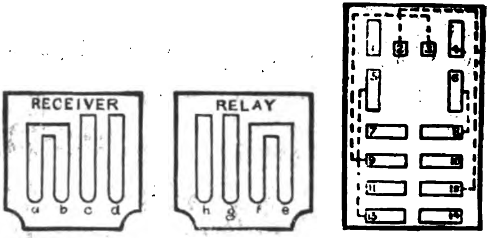

FIG. 413.—Peg switch used in connection with the leak circuit of duplex repeaters.

The connections of the leak circuit and switch are indicated in Fig. 414. When working duplex, the peg is inserted vertically, and when the relay side faces the left the following connections are made:—7 to 8 by *h* and *d*, 9 to 10 by *g* and *c*, 11 to 13 by *f* and *e*, 12 to 14 by *b* and *a*. The springs *d* and *h* and *c* and *g* are respectively connected together by screws passing through the body of the peg.

Reversal of the peg joins 7 and 9, 8 and 10, 11 and 12, 13 and 14, so connecting the receiver to the down and relay to the up transmitting relay.

At simplex the peg is placed horizontally and with the receiver side of the peg facing the front 1 and 2 and 4 and 6 are joined.

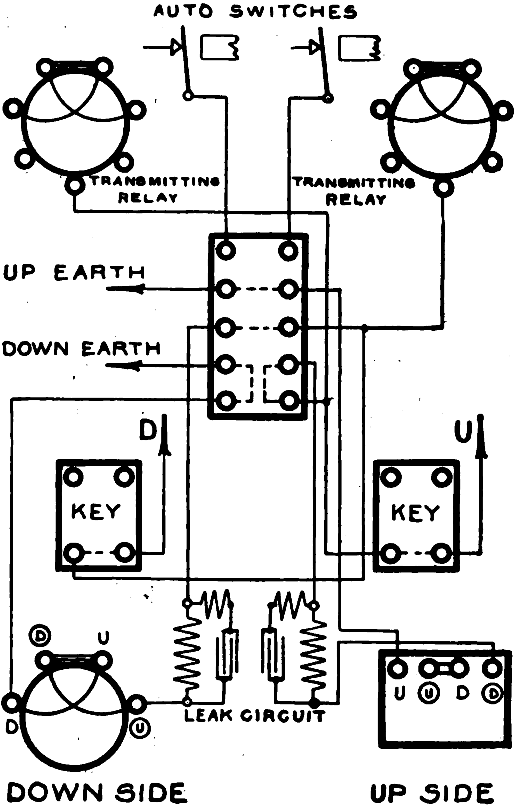

Fig. 414.—Leak circuits upon a duplex repeater.

The general arrangement will, however, be quite apparent from Fig. 414.

It may be pointed out here, that should the distant stations be reversed, as frequently happens with the system of night concentration now in use, they are able to work to one another through a repeater, as the transmitting relays repeat the currents in the direction they are received. At the repeater station, however, the signals in the leak circuit would be reversed.

DUPLEX REPEATER FOR CABLE CIRCUITS.

Cable circuits are usually worked upon the bridge duplex system in order to obtain a higher speed than is possible with the differential duplex; but since the speed of the land line is invariably greatly in excess of that of the cable, the land line is worked as a differential duplex in order to economize in apparatus. This arrangement contains no new principles, and it is believed that the skeleton diagram given in Fig. 415 is sufficiently explicit. A view of such a repeater is given in Fig. 416, and it may be pointed out that the receiver is placed in a similar position to that shown in Fig. 412, and that the sounders, etc., are placed upon the shelf above the board. The large condensers

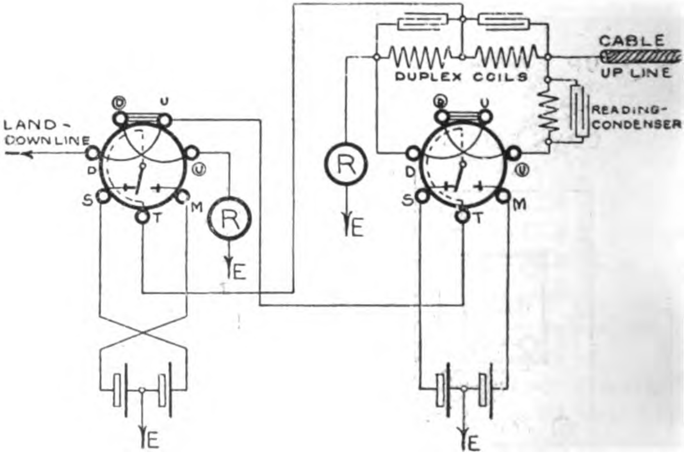

FIG. 415.—Skeleton connections of a duplex repeater working upon the bridge method on the cable side.

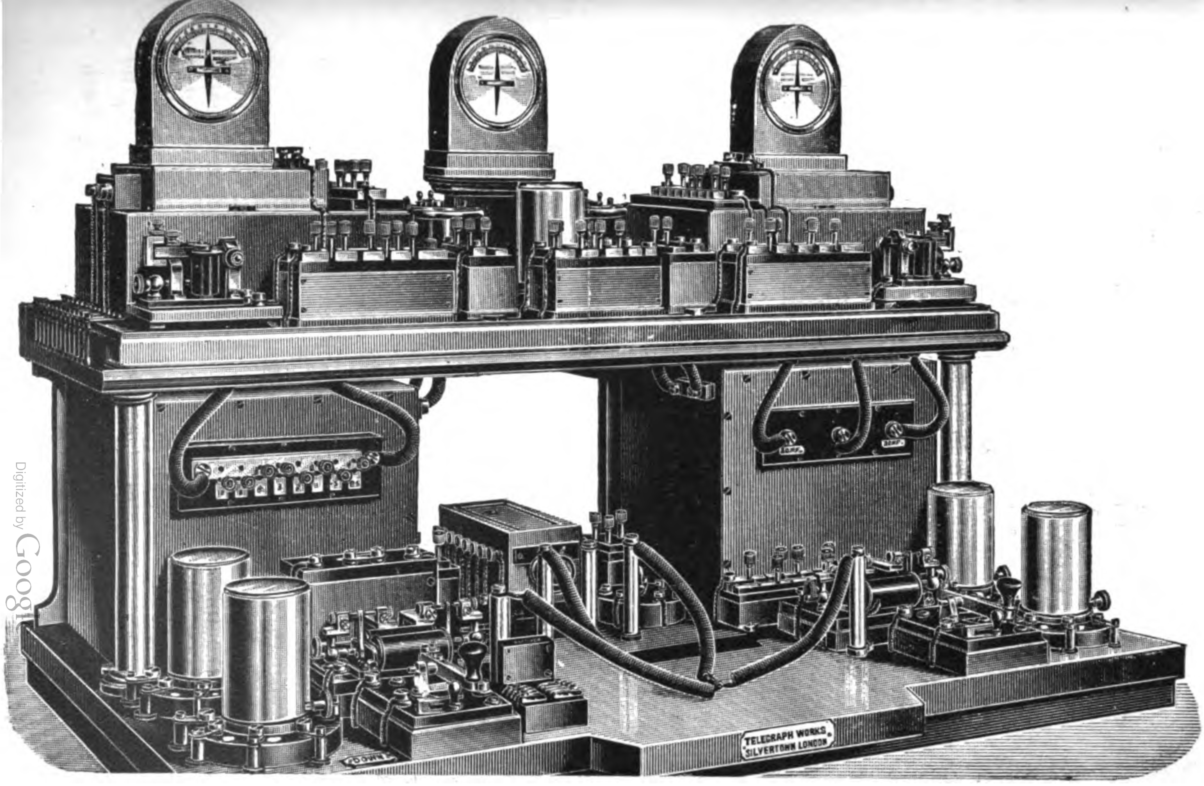

FIG. 416.—Duplex repeater board for bridge working upon the cable side.

required for balancing and for signalling on the cable side are mounted upon the up and down sides of the board, whilst the land line balancing condenser is fixed upon the shelf. The third galvanometer is in the leak circuit. In balancing Wheatstone duplex repeaters it may be mentioned that as there is no transmitter at the relay station, reversals are obtained from the distant station and passed into the line which is being balanced to obtain a clean slip.

At Preston the repeaters on the Northern Underground are worked on the bridge duplex system on both sides.

Long underground circuits working with high speed apparatus are fitted with repeaters when the lines exceed about 200 miles in length. In some cases the required speed is obtained with differential connections on both sides, but in others, when the repeater cannot be placed near to the electrical centre, bridge working on the longer side may be necessary, or in some instances on both sides. A new form of repeater has been designed to provide either differential or bridge duplex connections on either side independently by turning over a switch. Another improvement introduced into this repeater consists in fitting the relays with rectangular bases and providing contact springs for making the connections. In this way a relay would be adjusted prior to placing it in position, and to change a relay occupies but a moment, since there are no wires to remove from screw terminals.*

FORKED REPEATERS.

There are cases in which it is necessary to repeat to two or more offices situated in opposite directions; for example, London transmits news to Belfast and Cork with the aid of a forked repeater at Dublin. This object may, of course, be accomplished by using an ordinary simplex repeater with the Dublin-Belfast and Dublin-Cork lines connected together to the down side. In this case it will be obvious that, since Cork and Belfast are both down offices, the signals sent by Belfast would be received reversed at Cork, and Cork's signals would be reversed at Belfast, but both offices would, of course, read London correctly, and, similarly, London would be able to read both. The forked repeater was designed to enable the "fork" offices to read each other's signals, and, in the apparatus about to be described, provision is made for Wheatstone working from all offices.

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* Abstracted from an article, "Telegraph Repeaters," by A. C. Booth, *P.O.E.E. Journal*, Vol. VII. p. 317.

By means of a 6-bar switch the forked repeater may be converted into a simplex repeater of the type illustrated in Fig. 410. It will, however, suffice to indicate the principle of the arrangement by means of a skeleton diagram.

The forked repeater contains four galvanometers (one in the leak circuit), three transmitting, three auto-relays, three auto-switches, and two relaying sounders.

PATH OF CURRENT.

Referring to Fig. 411, it will be seen that a current from the up station passes to earth via the right-hand lever of auto-switch 1, up transmitting relay, rheostat, and up auto-relay. The latter relay closes auto-switches 2 and 5. The current from the up transmitting relay passes to the down line 1 via the right-hand lever of auto-switch 2 and to down line 2 via the left-hand lever of auto-switch 5. A portion of the total current also passes through the leak circuit via the left-hand lever of auto-switch 2. A current from down line 1 passes to earth via the right-hand levers of auto-switches 2 and 3, the left-hand down auto-relay in parallel through the down transmitting relays and the rheostat. The left-hand auto-relay closes auto-switches 1 and 4 and the current from the left-hand down transmitting relay passes to the up line via the right-hand lever of auto-switch 1, whilst the current from the right-hand down transmitting relay passes to down line 2 via the [illegible] hand levers of auto-switches 4 and 5 and to the [illegible] circuit via the left-hand levers of auto-switches 4, 3 and 2.

A current from the down line No. 2 passes to earth via the right-hand levers of auto-switches 5 and 4, right-hand down auto-relay, in parallel through the down transmitting relays and the rheostat. The right-hand down auto-relay closes auto-switches 1 and 3, and the current from the left-hand down transmitting relay passes to the up line via the right-hand lever of auto-switch 1, as in the case of the current from the down line 1, whilst the current from the right-hand down transmitting relay passes to down line No. 1 via the right-hand levers of auto-switches 3 and 2 and to the leak circuit via the left-hand levers of auto-switches 3 and 2.

It will thus be seen that the signals are "straight" to all stations, and that the down stations are enabled to read each other's signals.

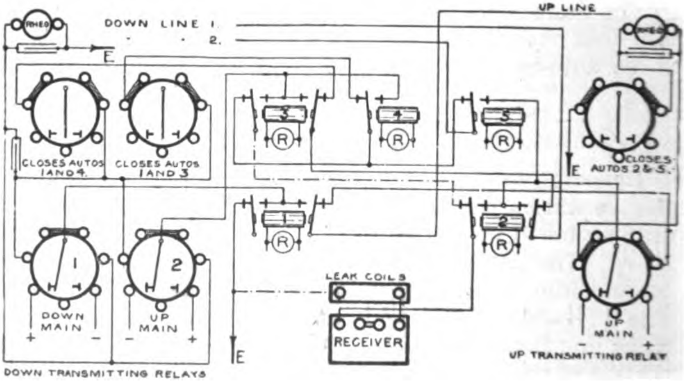

Fig. 417.—Principle of forked repeater.

A 6-terminal 2-position switch is added to the board in order that the condition of the signals sent out, upon either of the down lines, may be observed. The key for corresponding with the terminal stations is of the reversing key pattern, but has a send and receive switch equivalent to three mechanically connected two-way switches. This is necessitated by the fact that signals are simultaneously sent out to the three lines: one side of the key is used for the down lines, whilst the other side sends out currents upon the up line.

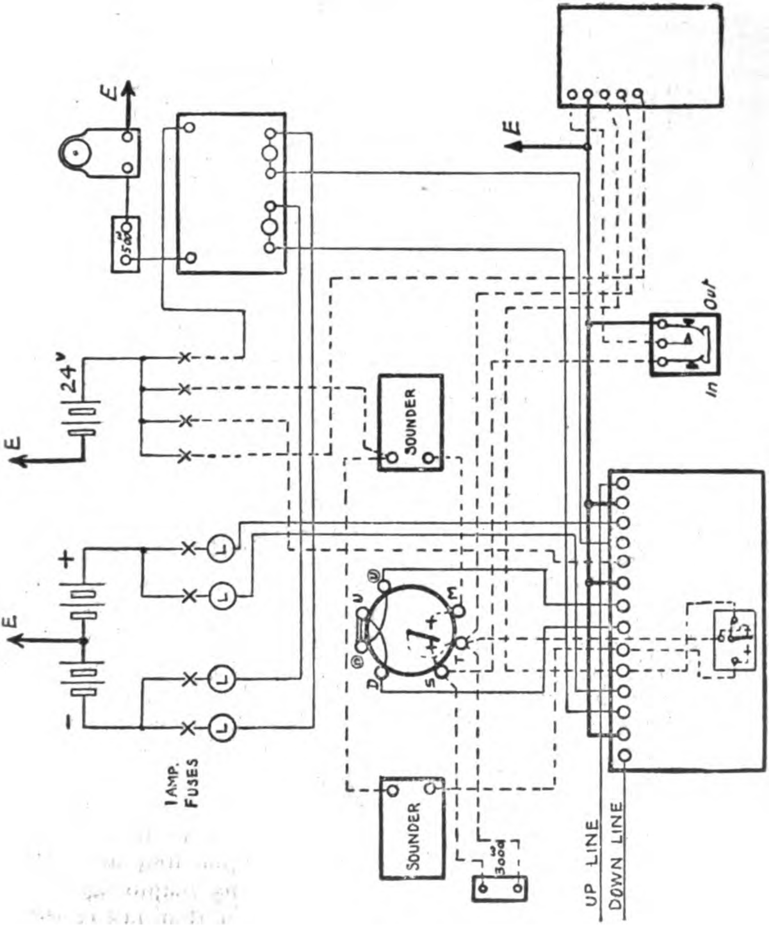

FIG. 418.—External connections of a repeater.

EXTERNAL CONNECTIONS OF A REPEATER BOARD.*

The Post Office repeater stations are now all equipped with secondary batteries and Fig. 418 gives the external connections. The indicators are of the drop shutter type, non-polarized, 100ω resistance with the coils in multiple, and they have a 10ω shunt. They are placed in the main negative battery leads. They are adjusted not to respond to the ordinary working currents. The indicators give warning of any short-circuiting of the batteries at the transmitting relay contact points or a near earth on the line, through being actuated by the resulting heavy current. The armature of the indicator closes the circuit of the 24 volts local set through a bell. A further indication is given by the lamp resistances, in the battery leads, glowing brilliantly. The sounder silencer is dealt with later in the chapter, and the remaining connections are self explanatory.

ADJUSTMENTS.

The transmitting and neutral relays should be carefully adjusted before being fixed on a repeater board. The working parts should move freely and the relay should respond readily to a current of ½ m.a. To obtain the best adjustment it is necessary to place the permanent magnet fairly close to the armatures. A suitable distance is about double the thickness of a Morse slip, and if the magnet is not an unusually strong one it will be found that the spindle is not magnetically pivot bound. It is well also to place the contacts in a neutral position so that the tongue will remain against either contact. Neutral relays in addition require the springs adjusting to keep the tongue midway between the contacts. To do this put the spring on the spacing side over the tongue first, and just put sufficient tension on this to hold the tongue against the spacing contact. The other spring is then put on the tongue and tension put on sufficient to bring the tongue midway between the points. For a very fine adjustment for fast-speed working close up the spacing contact till the local circuit is closed on that side, opening a trifle to break the connection, and then similarly on the marking side. In the later form of neutral relay with the flat spring extension of the tongue. the adjustment of the contact points is similar to that just described, the adjustment of the spring being made by increasing or decreasing its flexibility by lengthening or shortening its play. This is done by means of a screw attached to a groove which can be moved to enclose more or less of the end of the spring. This type of instrument is far easier to adjust, but experienced repeater clerks prefer the older form on account of its wider range and greater stability of adjustment, and this is specially so when the insulation of the lines is low.

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* *Connections of Telegraphic Apparatus and Circuits, G.P.O.*, plate 84 (1906).

In adjusting the auto-relay with spiral springs care should be taken that the least possible tension is given to the springs. When so adjusted there are, on the cessation of the current, two forces tending to restore the tongue to the midway position, since one spring is in compression, and therefore assists the spring which is in tension. When a considerable amount of tension is placed upon the springs, both are in tension when deflected, and uncertain working at once results. Where the adjustment has been carefully made it is by no means unusual for the relay to work for some weeks without re-adjustment.

The working speeds of all the most important Wheatstone circuits are tested each day, in order that the adjustments may be verified or corrected before the heavy traffic commences. The maximum working speed, known as the "standard speed" of each circuit, is stated at the time of its installation.

Prior to commencing the daily speed trials, the contact points of the transmitting relay should be burnished, and too much care cannot be exercised in this respect as sparking contact points necessitate repetitions and result in a reduction of speed through the points having to be opened to eliminate the sparking. In fixing a speed it is well to endeavour to prevent a short-circuit of the contact points. Whilst the transmitting relay is responding to reversals experience will soon enable one to close up the points to the finest possible adjustment without short-circuiting by placing the tip of a finger against the back of the relay tongue, thus readily noting the amount of play as the points are closed up.

Before putting a repeater to duplex it is advisable to see that resistance is put in the rheostats, otherwise fused apparatus may result.

FAULTS.

Whilst it is scarcely possible to schedule every fault which can occur upon a repeater-board, there are a few defects of common occurrence which may with advantage be here recorded. It is well to interfere with the adjustments of the spiral springs of the neutral relay as little as possible when once a satisfactory adjustment for general working has been obtained.

When a fault appears, it is unwise to alter any adjustment until the nature of the defect is known with certainty.

FAULT. *Auto-switch jumping whilst stations working.*

(1) Observe the incoming currents to see that both currents are received from the sender's key or if there is a line failure.
(2) If incoming currents are weak adjust both contact points of auto-relay to give a finer adjustment.
(3) Failing with these it may be necessary to clean the contact points of the auto-relay.

There should be no resistance in the rheostats of repeaters in circuit on newspaper wires worked by key.

FAULT. *Auto-switch jumping whilst circuit at rest.*

This is probably due to induction or contact. If due to induction :—

(1) Insert resistance in rheostat.
(2) Open contact points of auto-relay.

Lightning discharges also cause the auto-switch to jump. Possibly other repeaters would then be affected and the kick of the auto-switch is sharp and pronounced.

Fault. *Auto-switch sticking whilst circuit at rest.*

(1) Faulty adjustment of auto-relay.
(2) Faulty adjustment of auto-switch armatures.

When a station reports a current being left on at the repeater a glance at the galvanometers will usually suffice to show whether this is so or not. If both galvanometers show a deflection, the current is probably coming into the repeater from one side or the other. To make certain of this, put over both switches to "send," and if the armatures of the auto-switches are at once released the fault is not at the repeater. If, however, the levers fail to return to their normal position, the fault is with the repeater and must be at once attended to.

Fault. *Signals running together or failing.*

(1) Line fault,
(2) Sender's key faulty,
(3) Misfitting slip, or
(4) Contact points of transmitting relay dirty.
(5) If duplex confirm balances.

Fault. *Sending batteries short-circuiting.*

(1) Contact points of transmitting relay closed up, touching the tongue,
(2) Line to earth very near,
(3) Lightning protector short-circuited, or
(4) Key screwed down.

This fault would cause the indicator bell to ring.

Fault. When an office advises that they are *unable to gain the attention of the repeater clerk*, and it is found that no call is being received, the key switch should be put to ' send," and if the terminal station's current is received on the galvanometer the fault is likely to be in :—

(1) The right-hand lever of the auto-switch. If not there—
(2) Examine switch of key,
(3) Arms of rheostat,
(4) And all other connections of the incoming current.

Fault. *Weak signals in the leak circuit* might be due to—

(1) Too much resistance in leak coils.
(2) Faulty receiver adjustment, or
(3) Earth on line, close up to repeater. This latter fault might cause the indicator bell to ring.

Fault. *Signals unreadable at terminal station although good marks are obtained on the leak receiver.*

(1) Line fault, or
(2) Instrument fault at the distant station, or
(3) Right-hand lever of auto-switch not making good contact. (This is somewhat improbable.)

An earth fault is frequently caused by lightning discharges short-circuiting the protectors.

Faults occasionally occur in the galvanometers. Most frequently these are due to short-circuiting of the coils, as one coil of the galvanometer is always to earth. Galvanometer coils are often fused by lightning, and in some cases vacuum protectors have been placed across the galvanometer coils to protect them from injury. A disconnected shunt on the galvanometer would not permit a perfect balance to be obtained at duplex by means of the galvanometer and would be detected by balancing to clear the slip with reversals passing to line.

LOSS OF SPEED IN REPEATING.

The following results were obtained in experimental work. The tests were taken between three offices, *A*, *B* and *C*; *B* being the intermediate point.

Working direct *A* to *B*, the latter station receiving on a receiver, a speed of 375 words per minute was obtained: *B* to *C* under similar conditions, the speed was 363. With a repeater at *B* and *A* sending by transmitter to *C* the speed was 310, but the repeater station could now read 400 words per minute. The loss of speed *A* to *B* with a receiver at *B* would appear to be solely due to the mechanical inertia of the receiver. If it became desirable then to get the highest possible speed out of a wire it would be advisable to make the receiver part of the local circuit of a relay. The fact that the relay repeats 400 words a minute which can be read in the leak circuit whereas the distant station can only read 310 brings to light a fact which is generally overlooked, and this is that the leak is nearly a perfect circuit. Capacity being practically a negligible quantity in the leak and the self-inductance of the receiver being suitably balanced not only by the condenser but by the very high resistance in the leak circuit, the steady current value is almost instantly attained. The speed *B* to *C* direct from a transmitter is 363 as compared with 310 from *A* to *C* relayed at *B*. Even with the elimination of the galvanometer, neutral relays, leak circuit, etc., merely leaving the transmitting relay at *B*, the speed *A* to *C* could not be increased beyond 310. The only conclusion in determining where the loss of speed takes place would appear to be that it is due to the difference in the nature of the impact at the transmitter points as compared with those of the transmitting relay contact points.

QUADRUPLEX.

SPLIT QUADRUPLEX REPEATER.

By interpolating a split quadruplex repeater at the intermediate station *B*, three duplex circuits, viz. *A* and *B*, *A* and *C*, and *B* and *C*, can be provided on a single line wire connecting *A*, *B*, and *C* (Fig. 419).

The apparatus employed at the up and down stations are respectively ordinary up and down station quadruplex sets. At the repeater station each line is joined to a quadruplex set with certain additional connections, and, when the switches of the double current keys are turned to send, the up and down lines may be worked from the repeater station as two independent quadruplex circuits.

It will be recognized that the tongues of the down polarized and non-polarized relays follow the motions of the down station's *A* and *B* keys respectively, and that similarly the up repeater relays are controlled by the up station *A* and *B* keys. The non-polarized or *B* side relays at the repeater office are each provided with the standard local circuit for the reception of the signals sent on the out-station *B* keys. The repeater station's *B* keys determine the voltage, and the local contacts of each *A* relay determines the direction of the current sent to the other relay split. In other words, the tongue of the up polarized relay replaces the down *A* key, and the tongue of the down polarized relay replaces the up *A* key. The arrangement is in fact that of the ordinary duplex repeater with the non-polarized relays, and 6-terminal reversing keys added to provide *B* side working.

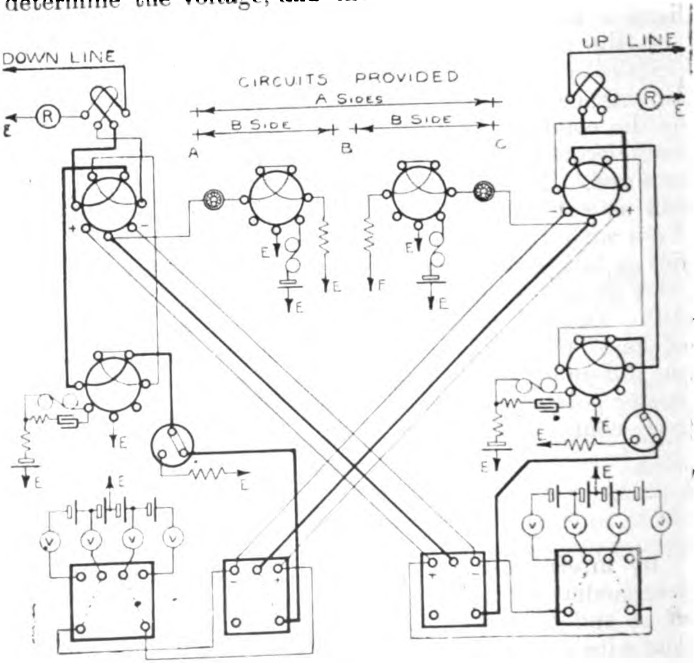

Fig. 419.—Split quadruplex repeater.

To trace out the currents in every position of the keys would be to repeat the majority of Chapter IX, and it will therefore suffice to indicate in general terms the effects which result when all the keys are depressed. The depression of the down station's keys bring over the tongues of the down repeater relays, which registers a mark on the repeater down sounder and reverses the current applied to the split of the up relay, thus causing a mark at the up station on the *A* side. Similarly, a mark is made on the *A* side at the down station by the reversal of the current by the tongue of the up *A* relay which moved over when the up *A* key was depressed. The depression of the up *B* key causes a mark on the repeater up sounder. As both repeater station keys are assumed to be depressed the higher voltage is applied via the tongues of the *A* relays to the lines, and therefore marks are made on the *B* sides at the up and down stations.

A leak circuit consisting of a polarized relay, tumbler switch and a resistance coil, is connected to each relay tongue for the observation of the outgoing signals.

By turning the switches of the double current keys to send, the keys substitute the tongues of the relays and quadruplex working to each station may be employed, the sounders of the leak circuits serving for the reception of the *A* side signals in each case. It will be observed that although the tongues of the relays are then separated from the *B* keys there are still positive and negative voltages connected to *S* and *M* in each case; but these are only operative in actuating the *A* leak relays at the repeater office.

A SIDE RELAYED DUPLEX.

This arrangement provides a duplex circuit between the terminal stations and one between the repeater or intermediate station and one of the terminal stations, whereas the split quadruplex repeater provides a duplex circuit to both terminal stations (Fig. 420).

The down line is joined to a duplex, and the up line to a quadruplex, set at the repeater station. The tongue of the *A* side relay, which moves in accordance with the up *A* key, performs the functions of the single current key with switch, and thus determines the directions of the current applied to the split of the down side relay, and hence the position of the relay tongue at the down station. The down relay tongue is controlled by the down station key and determines the direction of the current applied to split of the non-polarized relay, and thus the position of the tongue of the *A* side relay at the up station. The *B* side is used between the repeater station and the up station precisely as in the case of the split quadruplex repeater. The leak circuits are also arranged similarly save that a polarized sounder and condenser are used on *A* side leak. By turning the switches of the double current, and four terminal, keys at the repeater station the circuits are separated into a down station duplex and an up station quadruplex.

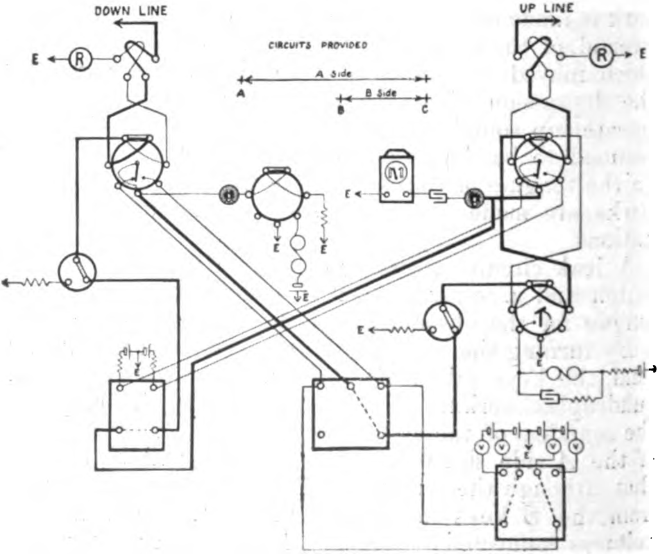

FIG. 420.—Quadruplex *A* side relayed duplex.

If it be required to relay from a down office to an up office, the quadruplex set is joined to the down line and the duplex to the up, suitable changes in the direction in which relays, galvanometers and batteries are connected being made.*

A Side Relayed Simplex Central Battery.†

This arrangement provides a duplex circuit between the terminal and repeater stations, and a central battery circuit between the terminal station and a central battery circuit radiating from the repeater station. This is useful in saving the labour of retransmission at the repeater office in cases where the work from the sub-office circuit is mostly for the terminal office (Fig. 421).

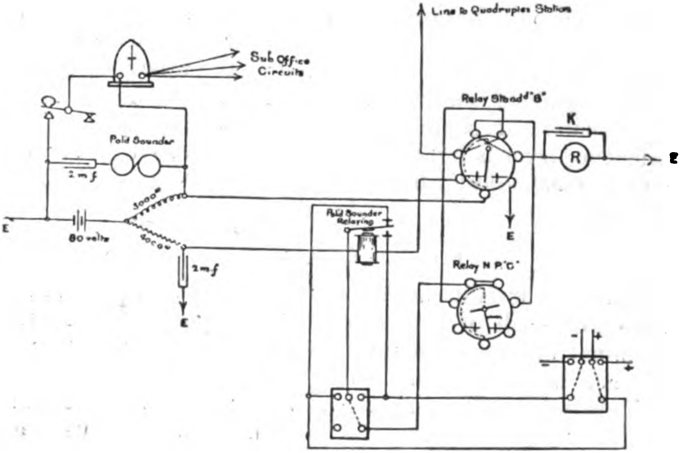

FIG. 421.—Quadruplex *A* side relayed simplex central battery.

The *B* side is used between the terminal and repeater offices as a duplex, whilst the *A* side provides for the central battery circuit, an ordinary quadruplex set being used at the terminal station. The tongue of the *A* side relay moves in accordance with the terminal *A* key, and in the marking position earths the central battery line, thus producing a mark at each of the out-stations. When at out-station signals by depressing his key the central battery line is earthed and the armature of the relaying sounder descends owing to the current flowing through its coils via the 4000ω resistance. The position of this armature determines the direction of the current applied to the terminal station, and hence of the terminal *A* relay.

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* *Connections of Telegraphic Apparatus and Circuits, G.P.O.*, Plate 76.

† "The Theory and Development of Central Battery Telegraph Systems." A paper read before the I.P.O.E.E., March 8, 1909, by J. Fraser.

It need only be added that switches are provided to divide the circuit into a quadruplex circuit, and a separate central battery circuit terminating at the repeater station.

The relaying sounder is very similar to an ordinary Vyle polarized sounder but placed on its side. The armature lever is light, plays between two contact screws, and is mechanically balanced by a counterpoise fixed to the other end.

FORKED QUADRUPLEX.

A duplex circuit can be provided between the terminal office and each of two offices over a single wire from the terminal office to the repeater office, and a wire thence to each of the two stations.

This involves relaying the *B* side as well as the *A* side at the repeater station. The terminal station uses an ordinary quadruplex, and the out-stations, duplex sets. The duplex line using the *A* side is connected after the fashion dealt with in previous quadruplex arrangements and calls for no further comment.

The local circuit of the *B* side relay (Fig. 422) is joined up to a standard relay with resistances and condensers as shown in order to avoid the *B* kick effect. The tongue of this relay follows the motions of the distant *B* key, and thus determines the direction of the current applied to the split of the relay in connection with line 2, and therefore the position of the tongue of the relay at line 2 out-station. The position of the key at out-station 2 determines the position of the tongue of line 2's relay at the repeater station. This determines the positions of the tongues of the two relays, termed in this connection the incrementer relays, connected to its local circuit, and therefore determines whether 40^v positive and negative, or 120^v positive and negative are supplied to the tongue of line 1's relay.

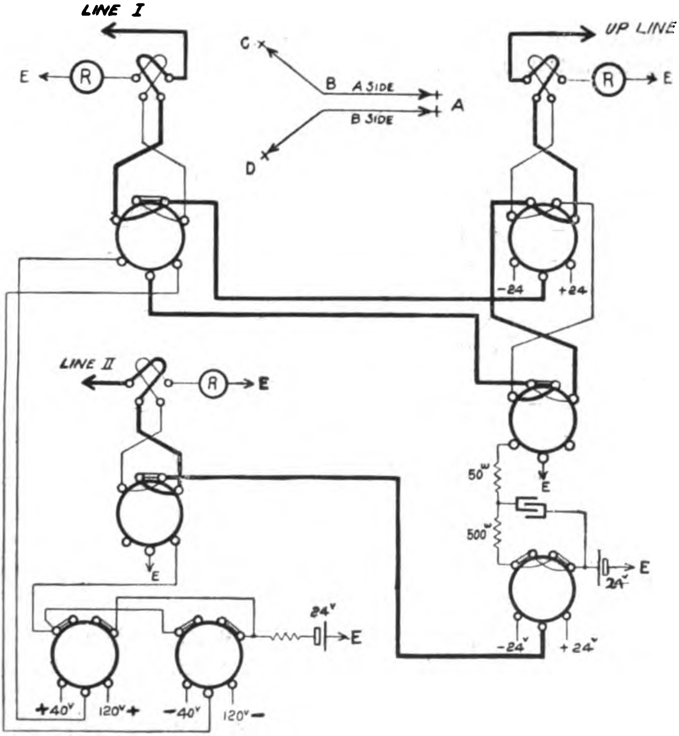

FIG. 422.—Forked quadruplex.

It will now be recognized that the tongue of line 1's relay performs the functions of an *A* key, and the tongue of line 2's relay those of a *B* key with respect to the quadruplex worked wire. Also, that the *A* relay performs the functions of a double current key in connection with line 1, and that the *B* relay signals on to line 2.

QUADRUPLEX REPEATER.*

In order to work over lines of very high *KR*, and in some cases to obtain Wheatstone working on the *A* side it is necessary to interpolate a repeater.

The principle of such a repeater is illustrated in Fig. 423. It differs from all the repeaters previously considered in the method of observing the condition of the transmitted signals.

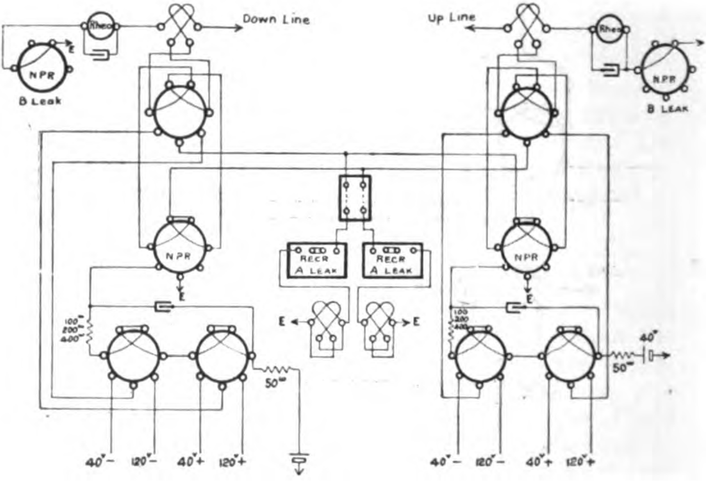

FIG. 423.—Quadruplex repeaters.

The up and down lines are joined to quadruplex sets at the repeater station; each *A* or transmitting relay determines the direction, and the corresponding *B* relay, with the aid of the incrementers, the voltage applied to the split of the other set of relays. In this way the signals received on each relay are repeated onwards.

In the compensation circuits a non-polarized relay is included for the observation of the *B* side signals sent out in each direction whilst the *A* side signals are judged by the up and down leak relays or receivers joined to the tongues of the *A* or transmitting relays. A galvanometer is also concluded in the *A* leak circuit, and by this means both the *A* and *B* currents can be noted.

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* An interesting account of the evolution of the quadruplex repeater is given in "The Quadruplex Repeater: experiments and working at Nevin," by J. N. McCurdy, a paper read before the I.P.O.E.E., January 28, 1907.

The condensers connected across the incrementers are to prevent breaks in the signals due to the *B* kick effect, and the resistance coil included serves to prevent large currents flowing through the relay contacts at the moment of closing the circuit. The device is in principle identical with that applied to the *B* side sounder on an ordinary quadruplex circuit.

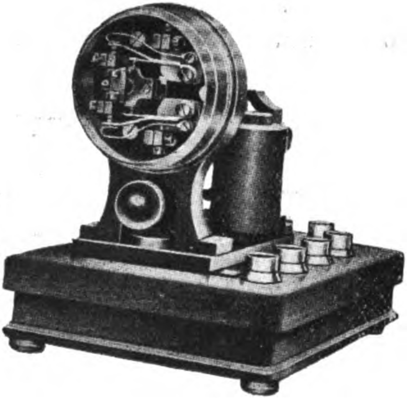

Fig. 424.—Automatic Telephone Co.'s polarized pole changer.

In earlier quadruplex repeaters a single instrument termed an incrementer (Figs. 310*a*, 310*b*, and 310*c* in the earlier editions of this work) was used in place of the pair of incrementer relays, but without success. The instrument is required to perform the functions of a 6-terminal reversing key, and it is arranged to give a momentary short-circuit whilst changing positions. Quite recently a pole changer with a Vyle electromagnet has been designed, and this instrument wound to $250^\omega + 250^\omega$ is capable of repeating signals at the rate of 430 as compared with 80 words per minute, the highest speed previously obtained with a pole changer. The device, illustrated in Fig. 424, gives a momentary short-circuit in changing position. The instrument seems likely to be useful in many directions.

Central Battery Repeater.

The insulation resistance of the line places a very definite limit on the length of circuit over which central battery working is possible. By introducing a repeater of the type shown in skeleton in Fig. 425 in the circuit very long circuits may be worked. Again, by adding transmitters and receivers it is possible to deal with an important speech or other emergency at a small office by using a repeater at the Head Office and extending the other side of the repeater to the stations to which it is necessary to work—with the relaying sounders a speed of about 130 words per minute may be attained, but by using the pole changer (Fig. 424) or standard relays instead, a much higher speed could no doubt readily be obtained. A large saving would result from the use of this plan, since no batteries would be required at the minor office and the arrangements generally would be of the simplest description.

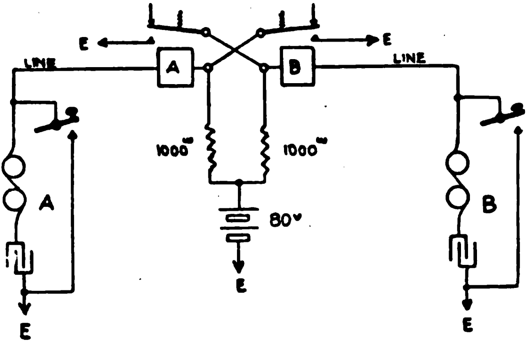

Fig. 425.—C. B. repeater.

The usual E.M.F. of 80^{v} is applied to each line through a 1000^{ω} feed resistance, but the coils of the two relaying sounders are interpolated in the line. The depression of the out-station key earths the line, and the resulting current through the relaying sounder draws down the armature which earths the other line and so produces a mark on the sounder by the discharge of its condenser. Keys are added so that the repeater station may signal to each office.

In connection with this arrangement, it may be remarked that it is necessary to prevent the discharge of the out station's condenser from affecting the polarized relaying sounders, and this is secured by placing only one coil of each polarized relay in the line and short-circuiting the other. In this way the energy of the short condenser discharge is taken up in inducing a current in the short-circuited winding, and thus leaving too little energy to actuate the polarized relay. This principle is frequently used in telephony to slow down the action of a relay.

HUGHES REPEATERS.

These repeaters, which are of the single current type are extremely simple, for, shorn of all the auxiliary apparatus, the simplex type consists merely of a pair of standard relays and batteries. In the simplex type (Fig. 426) the down line cable is taken to *T* of the up relay and via the *S* contact through the coils of the down relay, whilst the up line passes through the *T* and *S* contacts of the down relay and thence through the up relay coils. The transmitting batteries are joined to the *M* contacts of the relays. A current sent out from the down station passes through the coils of the down relay, thereby moving *T* over to *M*, and thus applying a positive current to the cable.

At the points marked *X* keys of the single current type with switch are inserted to enable morse signalling to be used between the repeater station and the terminal offices. In addition two relays with sounders connected with their local circuits are joined in leak and two Hughes sets also are provided in leak. The *S* contact of the leak relays are used in connection with the silencer (*q. v.*).

The 1000^{ω} inductance coil *L* is joined to the cable in leak in order to sharpen the signals. Its action is similar to that of a signalling condenser, for when an E.M.F. is applied to the cable it is, owing to the opposing E.M.F. set up, equivalent to a path of very high resistance, and this resistance gradually diminishes whilst the current is rising in its coils, until finally it would fall to its ohmic resistance. This condition is, however, never reached owing to the short duration of the signals. On the cessation of the signalling current the E.M.F. of self-induction acts in the same direction as the cable discharge and thus more rapidly discharges the cable.

The Hughes duplex repeater does not involve any new principles, and when the 8-bar switch is turned to simplex the connections become those illustrated in Fig. 411. At duplex the conditions are comparable with those of the ordinary fast-speed duplex repeater with bridge working on the cable side, save that the spacing battery on the transmitting relay is replaced by battery resistance coils. An inductive leak is applied to both line and compensation circuits.*

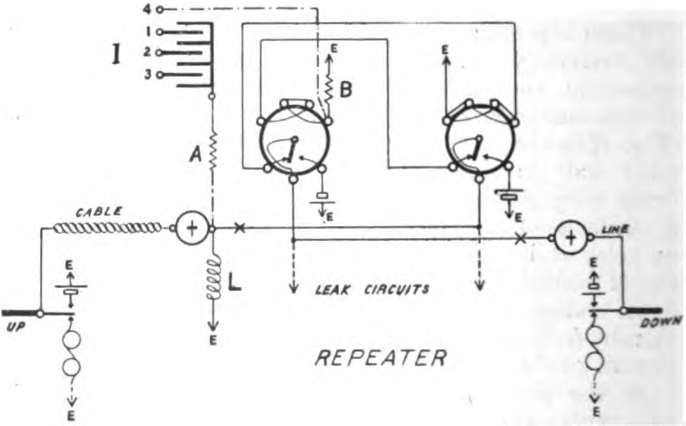

Fig. 426.—Hughes repeater.

The Anglo-German cables are roughly 300 miles long with resistances of 1600^{ω} to 2700^{ω} and capacities of 71 to 93 m.f., and it was found that, notwithstanding the brass taping of the cores, there is a certain amount of inductive interference between the four wires in each cable. This was not of great moment in simplex working, but in duplex working it is necessary to counteract it. The anti-induction device applied by A. C. Booth is shown by the broken lines in Fig. 426.*

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* The full connections are given on plate 92, *Connections of Telegraphic Apparatus and Circuits*, *G.P.O.* (1906).

Each signalling current sent from the repeater station into any one of the four wires in the cable produces inductively a corresponding but very much smaller current impulse in the reverse direction on each of the other three wires. These impulses pass from the cable through the up transmitting relays, but by applying to the relay a fraction of the original or disturbing current impulse equilibrium can be attained and the circuits freed from inductive interference. To accomplish this each cable wire is connected through a resistance coil having a resistance of several thousand ohms to one side of three condensers the other sides of which 1, 2, and 3 are respectively connected to the relays on cable wires 1, 2, and 3. The induced current, therefore, is opposed and neutralized by the current sent from the condenser, the latter dividing between the resistance coil *B* and the relay. Consideration will show that the condensers on set 1 are joined to the relays on sets 2, 3, and 4, that those on set 2 are joined to the relays of sets 1, 3, and 4, and on set 3 to 1, 2, and 4 relays.

In the case of duplex circuits the wire connecting res. *B* is joined up as in simplex working; but the condenser connections are taken to a point between the relay and rheostat of the disturbed circuits. The induced currents from the cable in the line coil of the relay are then opposed by the condenser currents in the compensation coil.

The precise values of the condensers and the resistance coils *A* and *B* are determined experimentally. Each condenser consists of twelve ·1 m.f. condensers, which may be arranged to suit the requirements of each case; the usual capacity is three ·3 m.f. condensers on each circuit.

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* "A Method of reducing Inductive Interference between Wire and Wire of a Telegraph Cable by means of Condensers," by A. C. Booth, *P.O. Electrical Engineers' Journal*, Vol. II. p. 209.

BAUDOT REPEATER.*

This type of repeater is interpolated on the Anglo-German cables passing through North Walsham. Since the Baudot is not worked simplex on these circuits, the type of differential duplex repeater is of a comparatively simple form. The repeater is, however, required for simplex Hughes working at night, thus necessitating provision for single current working, which is arranged by turning a switch to cut off the spacing voltage and replace it by a resistance. The cable section is kept always at duplex, and the aerial section is put out of balance sufficiently to avoid return signals to cable. There are other interesting features embodied in the repeater, for an account of which the reader is referred to the *P.O. Electrical Engineers' Journal.*

SOUNDER SILENCER.

Prior to the advent of the sounder silencer, invented by A. Eden and developed by H. R. Kempe and A. J. Stubbs, the greatest difficulty was experienced in detecting calling signals from amongst fifteen or twenty repeaters working simultaneously in a comparatively small room. With the silencer the whole of the local circuits containing sounders are normally disconnected, but may be joined up, as desired, at the will of the repeater clerk, or the relevant sounder may be brought into circuit by either of the terminal stations upon any repeater circuit. In order to call the repeater station the terminal office holds down the key for twenty seconds, and then gives the calling code.

One silencer electromagnet is required for each repeater, and acts as a silencer for both the leak sounders. The silencer cabinet contains a clockwork motor which rotates a wooden roller slowly round its axis. This roller is 18 inches long and has twelve rubber bands $\frac{5}{16}$ inch wide round it at distances $1\frac{3}{16}$ inch apart, and the cabinet accommodates twelve silencer magnets. These electromagnets are wound to 1000^{ω} and are fitted with 1000^{ω} shunts.

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* "Telegraph Repeaters," by A. C. Booth, *P.O.E.E. Journal*, Vol. VII. p. 317.

A brass lever A carries the armature of the electromagnet at one end, and it has a brass knob at the other end, together with a pawl L, the whole being pivoted horizontally, so that the knob end overbalances the armature end.

The armature lever controls two flat spring contacts S_1 and S_2, playing between the three contact points and an ivory stop point (C_1 and C_2 only are shown).

The pawl of the electromagnet rests upon the rubber band on the rotating barrel C, against which it is held by the spiral spring S_3; and thus it counteracts the inequality in the balance of the armature lever, so controlling it that the knob end of the lever falls gradually when the current through the electromagnet is broken. In ordinary working the spacing currents quickly follow the marking currents, and the pawl on the lever prevents the armature from rising. The adjustment is such that the springs S_1 should be brought into contact with C_1 and S_2 with its upper contact in from 14 to 18 seconds.

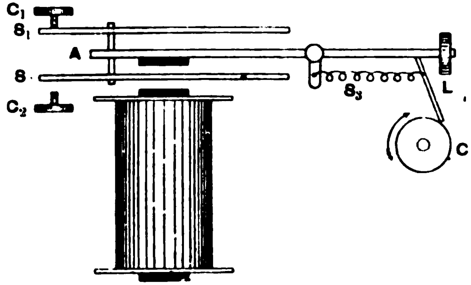

FIG. 427.—Principle of sounder silencer.

Fig. 428 gives the silencer connections.*

With the silencer operative the current through the electromagnet finds earth through the receiver, relay, and press button. When a marking current is received in the leak relay or the receiver this earth is cut off, and if the paths for the currents are traced out it will be observed that they are now in opposition at the electromagnet, hence this ceases to be energized. If this occurs for from 14 to 18 seconds the flat springs make an earth connection through the two upper contacts. When this happens the tongues of the receiver and relay are both earthed through the flat springs, and thus the local sounder connection is completed when the tongues are on the marking side.

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* "Sounder Silencers at Telegraph Repeater Stations," by J. J. Hardie, *P.O.E.E. Journal*, Vol. II. p. 121.

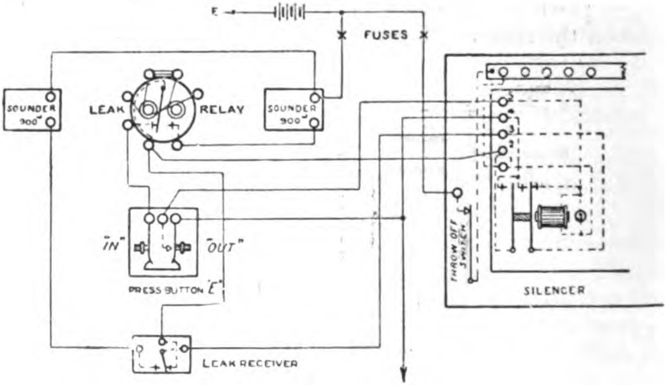

Fig. 428.—Connections of sounder silencer.

The depression of the button marked "Out" energizes the silencer magnet and the armature is pulled down. Whilst the button is depressed, however, it will be seen that an earth is also put on the tongue of the receiver and the sounder circuit is operative until the button is released.

The depression of the button marked "In" cuts the earth off the silencer magnet, and by this means the sounders can be brought in at the repeater.

Circuit Silencer.*

A single set of clockwork is necessary for the whole of the sounders which it is necessary to silence in any given office, and where there are several to be dealt with the sounder silencer is invariably employed. The cost of the device per circuit is extremely high where but one or two sounders have to be silenced, and accordingly a new instrument termed a "circuit silencer" has recently been designed.* This instrument is also largely employed upon those circuits which are led into offices for the transmission of service messages concerning the testing of wires passing the test-boxes of the offices in question. The number of messages will not be sufficient to justify the use of a circuit for this purpose alone, and the ordinary channels may involve retransmission, thus incurring delay. It is also in use at repeater stations,

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* "Sounder Silencers at Telegraph Repeater Stations," by J. J. Hardie, *P.O.E.E. Journal*, Vol. II. p. 121.

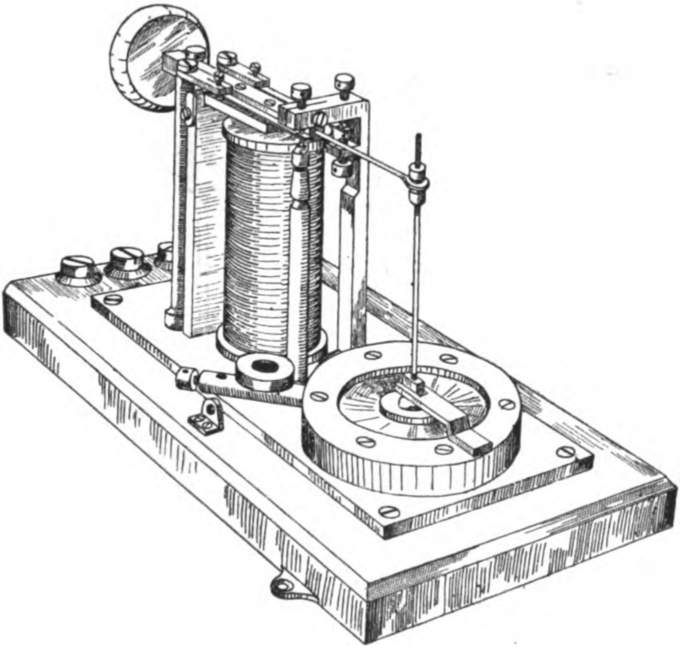

FIG. 429.—View of circuit silencer.

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* By H. R. Kempe.

where about fourteen silencers are required, as the silencer cabinet only contains twelve electromagnets.

The circuit silencer is shown in perspective in Fig. 429, whilst the detail of the pneumatic regulator and valve is shown in Fig. 430. The electromagnet is connected with a local battery between *T* and *S* of the relay upon the circuit to be silenced, and therefore every spacing current causes the armature to descend. The end of the armature is connected to the centre of an oiled silk diaphragm which can move downwards quite freely by expelling the air from the chamber through the outlet valve. The air inlet is, however, regulated by the platinum cone, and may be made as small as is required. If the key at the terminal station is held down for about 15 to 20 seconds the chamber fills with air and the armature rises to its full extent, thus bringing in the sounder. It may also be interesting to notice that the effects of residual magnetism have been employed to prevent the apparatus acting when Wheatstone signals are being sent over the circuit. The armature is allowed to bank down on to the cores of the electromagnet, and this no doubt very greatly increases the sluggishness with which the instrument works.

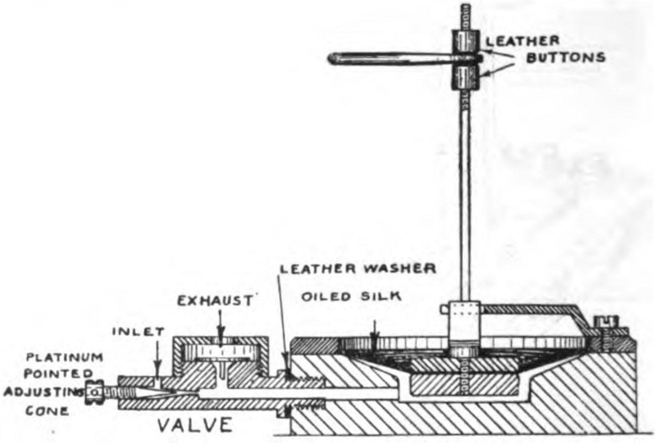

FIG. 430.—Details of outlet valve and air inlet.

SILENCER WITH CONDENSER AND MEGOHM RESISTANCE.

Donald Murray suggested a form of silencer in which the timing effect of a megohm resistance in charging a condenser is made use of.

When the relay is spacing the battery is cut off, but with the tongue against the marking contact the condenser is gradually charged through the megohm resistance. The condenser stores up sufficient energy in about 15 seconds to produce a sharp kick on the sounder as the discharge current passes through the sounder coils on the relay tongue moving to spacing again.

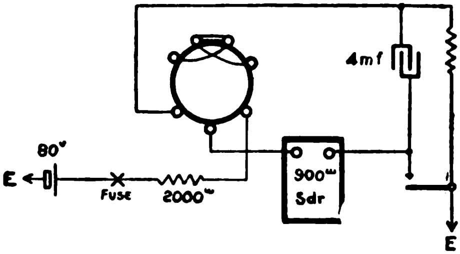

FIG. 431.—Silencer with megohm resistance and condenser.

The sounder is fixed on a base containing the condenser and the megohm resistance. The mechanical arrangement is such that the sharp downward kick of the armature of the sounder overbalances a pivoted lever which in falling forward raises the earth-connected lever, thus putting the sounder into circuit. The catch is replaced manually.

A later improvement consists in arranging that the condenser discharge shall pass through and actuate a drop indicator, which rings a bell. Thus, the adjustment of the sounder may be made without risk of throwing the silencer out.*

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* *P.O.E.E. Journal*, Vol. VII. p.

HUGHES SILENCER.*

Since the normal signals consist of short currents separated by unequal intervals of time an extremely simple form of silencer requiring neither clockwork nor spacing currents can be used. It consists of a large wheel *w* mounted on a common base with the sounder. Near the edge of the wheel an adjustable counterweight is fixed so that the projecting pin *p* holds up the sounder armature by means of the armature extension lever *e l*. Hughes signals tend to push the pin *p* downwards, but the inertia of the wheel is such as to prevent the depression of the armature. But when a dash or Morse signal is sustained sufficiently long to depress the lever fully, and thus turn the wheel, leaving the pin *p* on the left, the sounder armature is freed to receive the signals. The wheel is reset by hand on conclusion of the communication.

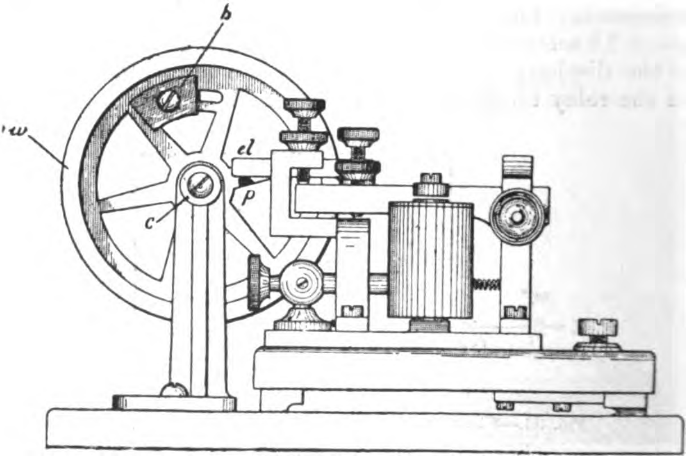

FIG. 432.—Hughes silencer.

It will be observed that the sounder is brought in without the usual "wait" of 20 seconds. The instrument was designed by the German Telegraph Administration and has been in use at Emden for many years.

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* "Sounder Silencers at Telegraph Repeater Stations," by Jas. J. Hardie, *P.O. Electrical Engineers' Journal*, Vol. II. p. 121.

CHAPTER XX

THE TEST BOX AND PROTECTIVE DEVICES.

PART I.—THE TEST BOX.

PRINCIPLE AND GENERAL ARRANGEMENT.

THE test box provides a point from which tests and circuit changes may readily be made. In very small offices where there are but two or three instruments the wires are directly connected to the apparatus, unless there are through wires led into the office for testing purposes.

The older form of test box consists of a number of terminal screws, mounted upon a vertical wooden baseboard, and suitably connected together by brass links.

The function of the test board is to provide facilities for testing operations and for circuit and apparatus changes. This provision is unnecessary at very small offices having but two or three instruments, and, unless through wires are led in for testing purposes, the line and battery leads are taken direct to the instruments.

The line portion of the terminal pattern test box consists of a series of vertical rows, each consisting of seven terminal screws mounted upon a vertical board, and suitably connected together by brass links. The central row of terminals, which are of blackened brass, serve as the common earth connection for two sets of apparatus (*vide* Figs. 433 and 435). Usually, up lines are placed at the top and down lines at the bottom, but this arrangement is sometimes departed from to economize space.

The connections of one end of a down station double current sounder are shown in detail in Fig. 433. The up and down instrument terminals are respectively connected to *U*-circle of the relay and to the galvanometer by two leads from the test box to the instrument table. Two brass links at the test box connect the set to line and earth, whilst the batteries are linked up on the battery panel. Each battery occupies four terminals, *Z* being on the left of each pair.

At small offices, separate panels are provided for terminal circuits, through circuits and batteries. The teak panels are hinged on the left to afford access to the connections at the back and the box is fitted on the wall at a convenient height. The dimensions of the box shown in Fig. 434 are 2 feet 8 inches high by 3 feet 4 inches wide. Its terminals are made with a stout pin which projects behind the panel and the wires are wrapped around and soldered to the pin. It is essential that resin be used as the flux when soldering owing to the corrosive effect of the various soldering fluids.

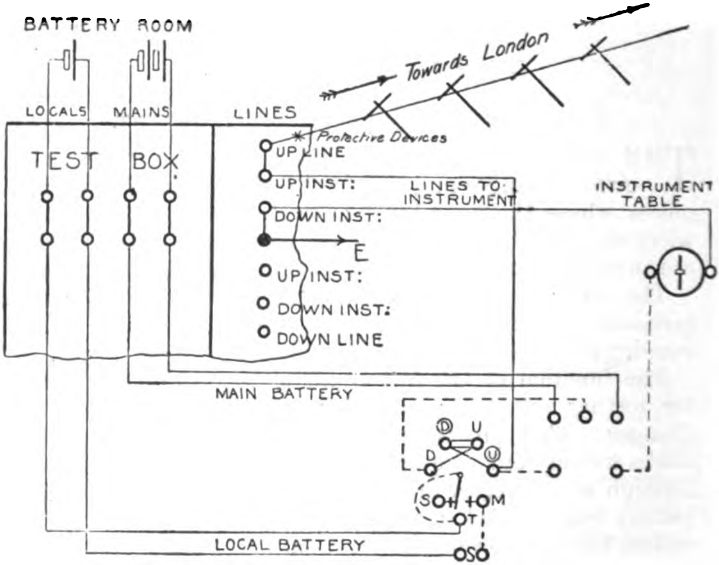

FIG. 433.—Test box connections of a double current sounder circuit.

At larger offices having many circuits, it is necessary to arrange the wires in route order to facilitate the tracing of contact faults and also to preserve orderliness in wiring, In such cases, through circuits and intermediate circuits are placed with the terminated circuits following the same route, and above group a label is fixed showing the name of the route. For instance, a route of twelve wires going to "B" via the "Y" canal would be labelled "B via Y canal" to distinguish them from a route on the road

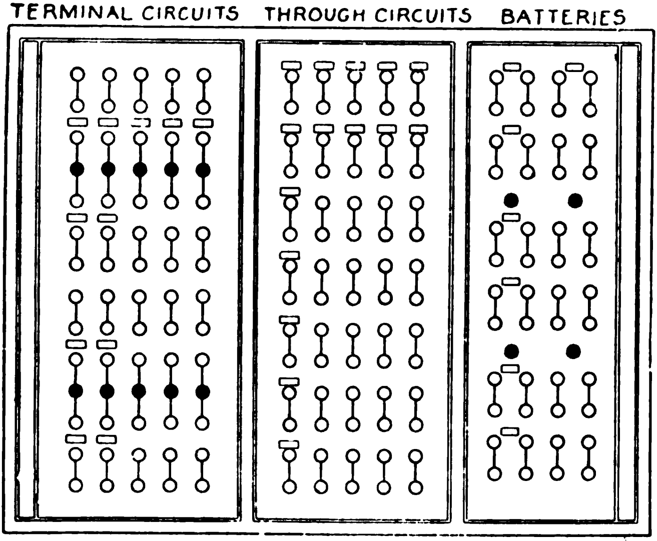

FIG. 434.—Arrangement of test box for a small office.

labelled "B road." It will therefore be recognized that each through or intermediate circuit occupies two sets of terminals, since the up and down sides are placed with the wires following the same routes. The connections required between the two sets of terminals indicated by dotted lines (Fig. 435) are made behind the box.

Fig. 435, with the table beneath it illustrate the various changes ordinarily required to be made. The precise object of the various operations is dealt with under testing in Part II of Chapter XXI, but it may be well here to emphasize the necessity to join up the apparatus correctly as regards up and down stations.

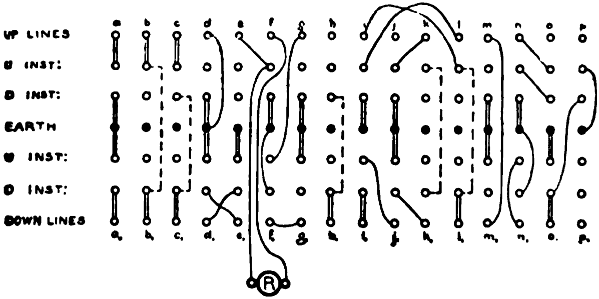
UP LINES
U INST:
D INST:
EARTH
U INST:
D INST:
DOWN LINES
a b c d e f g h i j k l m n o p
a_1 b_1 c_1 d_1 e_1 f_1 g_1 h_1 i_1 j_1 k_1 l_1 m_1 n_1 o_1 p_1
R

Fig. 435.—Illustrating various test box changes.

Terminal circuits.—*a* down station set, a_1 up station set.
Intermediate circuit.—*c* c_1 down set on *c* line ; down instrument terminal connected to c_1 line by connection made behind the box (dotted line).
Through circuit.—*b* and b_1.
To earth a line.—*d* is earthed ; the line link is removed.
To disconnect a line.—*h* ; the line link is removed.
To loop lines.—f_1 and g_1 lines are looped ; line links are removed.
To reverse.—n_1 set is reversed, *i.e.* made down station.
To join through.—*m* and m_1 lines are joined through ; *m* and m_1 sets are spare.
To divide a through wire.—*k* line is on *j* set and k_1 line on j_1 apparatus.
To fork lines.—*e* and *f* lines are forked on to *f* set and resistance inserted in line *f*.
To form a metallic circuit.—i_1 and j_1 lines are used by the i_1 apparatus.
To tap a circuit.—*o* set is placed in series with the *n* line and *n* apparatus.
To come in on a circuit.—Remove one line link and join in the apparatus to be used.
To cross sets.—d_1 and e_1 sets are changed over.
To cross lines.—*i* and the up side of *l* lines are changed over.
To terminate k k_1.—Both up and down sides are terminated on *j* and j_1 sets.

The connections are made with short lengths of insulated wire.

BATTERY TEST BOX.

The battery test box or panel should need little comment; in fact, a comparison of Figs. 433 and 434 should make the arrangement sufficiently obvious.

To increase the power.—Remove the link connecting *C* of the battery to the instrument and join the former to the *Z* of the battery to be added. The *C* terminal of this battery is then connected to the *C* instrument terminal.

To cross two batteries.—All four links are removed and then *Z* and *C* of the first battery are respectively connected to the *Z* and *C* instrument terminals of the second set of apparatus. Similarly *Z* and *C* of the second battery are respectively joined to *Z* and *C* of the first instrument.

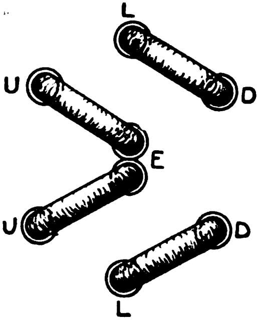

FIG. 436.—U-link test box line and instrument connections.

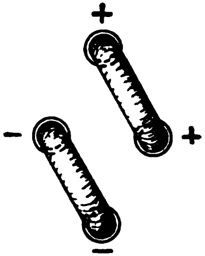

FIG. 437.—U-link test box battery connections.

U-LINK AND SWITCH SPRING TYPES OF TEST BOARD.

The 96 line test board consists of four ebonite tablets mounted in a cabinet of similar general design to that shown in Fig. 438. The two line tablets, each of which consists of 48 sets of four test holes, are placed side by side, and beneath them are placed two 40 circuit battery tablets. Each line circuit occupies four test holes arranged as shown in Fig. 436, and connected together by U-links. The two sets are with the links in the position shown joined up as up stations. By linking line with *U* and earth with *D* instrument the set may be reversed, whilst a link vertically placed between *L* and *E* earths the line. The distances *E U*, *E L*, and *E D* are made equal.

In the case of the battery test holes (Fig. 437) the spacing is such that the battery cannot be short-circuited by a wrongly placed U-link. The upper and lower holes are connected to the battery and the central holes to the instrument leads.

The line and battery test holes are connected to cross-connection strips in the base of the test board, and in the case of the line tablets cross-connecting facilities are provided by duplicating cross-connection strips of the line test holes. The object gained is explained in detail in the case of switch spring test boards (page 685).

A larger U-link test board accommodates 240 lines, but in this case the terminal circuits are earthed at the instrument table, and two test holes only are provided for each circuit. Reversing switches are added to a number of circuits which are used for special arrangements. Each of the four tablets contains ten vertical rows of nine test holes. The first six horizontal rows of test holes accommodate 30 lines and instruments, and the three remaining rows are left for intermediate returns, etc. (see page 686). At an office requiring a test board of this size secondary cell working would be in use, and therefore battery panels are not provided.

These U-link test boards are far more compact than the terminal type.

The switch spring test board is remarkable for its compactness, and by reason of the fact that normally there are no connections on the face of the board, such connections being required only when it is necessary to make circuit changes or for testing operations. It is in use only at offices where secondary cell working is in vogue.

As in the 240 line U-link board the earth connection of each instrument is made at the instrument table, thus saving wiring and test board space. Reversing switches are provided on a number of selected instruments, and special sets for intermediate working are also provided. In case of urgent need the relay connections could be reversed at the table, and the battery connections with pegs and cords at the distribution and fuse case.

Each panel of the test board accommodates 120 circuits and also provides for the requisite number of transfer circuits, earthing, grouping, morning test looping, and intermediate return switch springs.

A sketch of the general arrangement of a two-panel test board is given in Fig. 438. It accommodates 240 circuits, and has a total width of but 4 feet 9 inches.

The 120 lines are brought to each panel of the test board in a 127-wire lead-covered table, the odd seven wires being provided as spares. The conductors are 20 lb.

copper wires insulated with silk and cotton, the whole being covered with a seamless sheathing of lead.

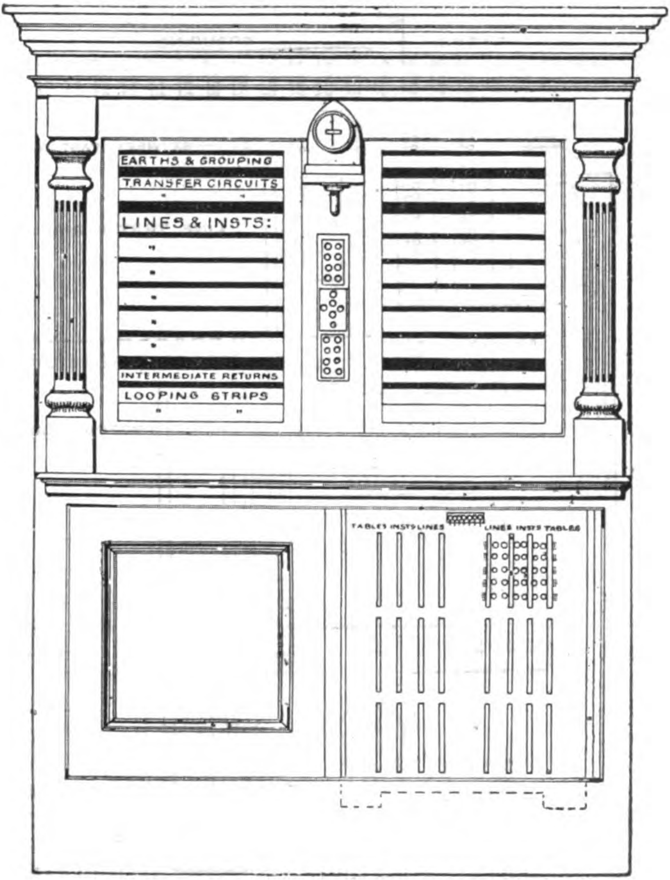

Fig. 438.—Two panel switch spring test board.

Upon the vertical board behind the front apron are placed twenty-four 20-tag cross-connection strips. Each strip consists of a square rod of ebonite with twenty tinned brass stampings placed within the slots prepared for their reception and held in place by thin strips of ebonite screwed down upon them. The brass stampings project

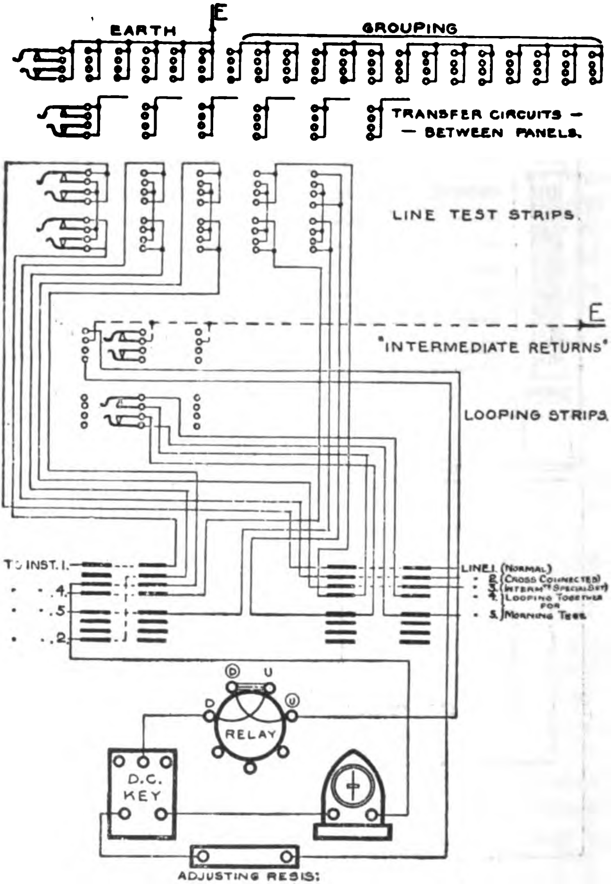

FIG. 439.—Principle of switch spring test board.

upon either side of the ebonite and have a small hole at each end through which the two wires to be connected are passed and soldered upon the top.

PRINCIPLE.

The principle and connections of the apparatus and lines to the switch springs will be apparent from a consideration of Fig. 439. No. 1 line is joined to the right-hand side of the line tag, which is connected through to the opposite tag by means of a bare piece of tinned copper soldered between them. The line then passes on to the upper or line switch spring, where it is connected to both long and short springs. The inner springs of the line switch spring are joined to the inner springs of the instrument switch spring, and the latter's outer springs are joined to the right side of the instrument tag. It is there connected to the left of the tag by a bare wire, and the left end of this tag is joined to the lead to the instrument table. By placing the springs in parallel in the manner indicated, the risk of a disconnection is greatly minimized.

CROSS-CONNECTING FACILITIES.

In each circuit there are two points bridged by short lengths of bare wire, and by removing them crosses and changes may be made without disturbing the line cable, cables to the instrument tables, or the connections between the switch springs and the tags. To change the permanent positions of two instruments of similar type it is only necessary to remove the bare wire connections between the instrument and table cross-connections, and to make the cross with single flame-proof wire 12½ lb. conductor. The wires used to form these cross-connections are taken behind the board, where suitable brass supports are provided for their reception. When it is required to cross two lines the changes are made at the main distribution frame. It will therefore be realized that crosses and changes of every description may be made without interfering with any connections other than those between the two pairs of cross-connection strips. The value of this provision in a large office can scarcely be over-estimated.

Line No. 2, which was originally joined to the apparatus connected to the second instrument tag, is shown cross-connected on to the apparatus in connection with the eighth tag. Without these facilities the lead from the table would have had to be manipulated and probably lengthened, and in the course of quite a short time the cables to the instrument tables would be jointed and would be scattered over the board in chaotic disorder.

TEST BOARD CHANGES AND TRANSFER CIRCUITS.

A number of circular brass pegs with fibre covers and connected together in pairs by flexible cord are provided for making circuit changes and for connections required for tests. Two switch springs are provided for each terminal circuit, and the insertion of a peg in line switch spring picks up the line on the outer springs which break contact with the inner springs. The other peg may be placed in another instrument switch spring, thereby joining the first line to this apparatus.

The top strip of twenty switch springs is used for earthing and grouping lines or instruments. The first six switch springs are earthed, and thus any line may be earthed by pegging it to one of these switch springs. Two sets of respectively three and four switch springs are connected as indicated for grouping wires together. For example, if it was required to fork No. 1 instrument to lines 2, 3, and 4, it would be necessary to plug No. 1 instrument, No. 2 line, No. 3 line, and No. 4 line on to the first, second, third and fourth switch springs of one of the groups.

In order to avoid the use of exceptionally long cords to reach from one end to the other of a large test box, a certain number of transfer circuits is provided. Each panel has twenty switch springs for this purpose, and these are connected in such a way as to provide a sufficient number of circuits to each panel of the board. A connection between two switch springs at opposite ends of the board is effected by means of two pairs of ordinary cords, one end of each pair being placed in the switch spring at either end connected to the transfer circuit used.

SPECIAL INTERMEDIATE SETS.

Line No. 3 is shown connected to an instrument fitted for intermediate working. In order to confine the attention to the principles involved the detailed apparatus connections have not been sketched. The line normally connected to the set passes through the line and instrument switch springs to the galvanometer in the ordinary way, but *U*-circle of the relay and the end of the adjusting resistance are taken to a special switch spring upon the "intermediate returns" strip. Under normal conditions *U*-circle of the relay is earthed through the inner spring whilst the adjusting resistance lead is disconnected. It will therefore be seen that No. 3 instrument normally works as a terminal station. When it is required for special work, as an intermediate set, the longer line is connected to the instrument and the shorter one to the intermediate return switch spring, the changes being made by two pairs of pegs and cords. By inserting one peg in the long line to be used and the other in the instrument switch spring, the long line's instrument is disconnected from the long line, the line normally connected to the intermediate apparatus is disconnected, and the long line joined to the galvanometer of the intermediate set. The short line is plugged through to the intermediate return switch spring which disconnects earth from *U*-circle and, since the plug is solid, connects *U*-circle and the adjusting resistance to the short line. The full connections of the apparatus were given in Fig. 401, which may now profitably be considered in relation to the foregoing paragraph.

LOOPING STRIP.

Lines No. 4 and 5 are also shown passing through a switch spring upon the looping strip. No. 4 line passes through the long spring and its inner spring back to the left-hand line tag, and so on to its line and instrument switch springs. No. 5 line similarly passes through the short and its inner spring. When an unconnected peg is inserted in the looping switch spring, lines 4 and 5 are looped through the peg. This provided a simple means of looping all those circuits which had to be looped each morning for testing purposes. In some cases the number was very considerable, and the tangle of cords upon the front of the box which would otherwise result was entirely avoided.

Moreover, the circuits were arranged upon the looping strip in the order of the times at which they were to be looped.

A test-hole tablet and a differential galvanometer, fixed upon a turntable, are mounted upon the vertical rail between the two panels. These testing arrangements will, however, receive further consideration in Chapter XXI.

PART II.—LIGHTNING PROTECTORS.

Each set of apparatus is equipped with a lightning protector, the function of which is to prevent the passage of the discharge through the apparatus when the line wire is struck by lightning. Most forms of protector consist essentially of a small spark-gap placed between the line wire and earth.

A lightning discharge differs from an ordinary telegraphic current in two particulars, viz. its high potential and the suddenness with which it occurs. A spark is produced when the electric strain upon the dielectric (air) reaches such a value that the air breaks down. The potential of a telegraphic current is very seldom more than about 200 volts, and this is insufficient to cause a spark of even the most minute dimensions. The currents are also comparatively slow in their occurrence, *i.e.* slow in comparison with lightning. Protection which would amply suffice for slow, heavy currents would be quite useless in the case of lightning. In order to make the distinction clear, the following analogies relating to mechanical inertia may prove of value. Let a quantity of gun-cotton be placed upon a slab of stone in the open air. Ignited with a match, nothing beyond a "fizz" will take place, but if fired with enormous rapidity by means of a detonator, the stone will be blown to fragments. The explanation is that, in the second case, the air above the gun-cotton, possessing inertia, will not move instantaneously with sufficient rapidity. The inertia resistance of the air is in this case clearly enormous, and it finds a parallel in the inertia resistance of the electromagnet to a lightning discharge. Yet another example of a similar phenomenon is the fact that a loose plug of snow in the end of a rifle is sufficient to cause it to burst when fired.

It has previously been pointed out that an electro-magnet possesses considerable inductance, and that the effect of this is to delay the rise of the current through it. The magnetic field, which is produced by a current, in springing into existence, cuts through the windings, and therefore generates an opposing E.M.F. termed the back E.M.F. of self-induction. This effect may correctly be regarded as electro-magnetic "inertia resistance." The resistance which would give an equivalent current when the E.M.F. in question was steadily applied to it is termed the "impedance." This quantity depends upon the rate at which the current rises, and means an equivalent resistance to that which would produce the value of current given by Ohm's law.

The equivalent resistance or impedance offered by the apparatus to a lightning discharge is enormous, and as the discharge is of sufficiently high potential, it breaks down the insulation of the air, and escapes to earth by the path of lesser resistance.

"C" PROTECTOR.

A "C" protector for two lines (Figs. 440 and 441) consists of two protectors mounted on a porcelain stabilit base, and in order to avoid risk of fire it is provided with an enamelled iron cover secured in position by a spring clip. Each protector consists of two carbon plates, between which three air-gaps are formed by the interposition of a perforated mica disc. The lower carbon plate is mounted on a tinned brass holder, which is fitted with a screw for attaching it to the terminal block. The upper plate is held in position by a clamping spring screwed to the earth-connected bar. The three radial holes in the mica disc are recessed from the solid mica in order to increase the length of the surface over which a leakage current has to travel from plate to plate. With a plain hole the length of surface is equal to the thickness of the mica disc, but with a recessed disc the current travels down the wall of the recess along and over the centrally projecting web along the recess and down the wall of the recess to the other plate. In this way the insulation of the protector is greatly increased, and the possibility of carbon dust abraded from the plates causing a connection is minimized.

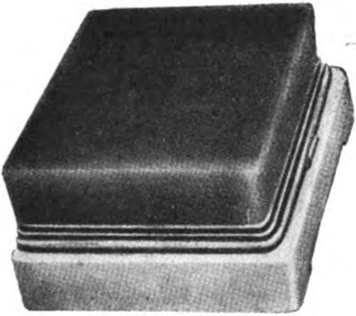

Fig. 440.—"C" protector.

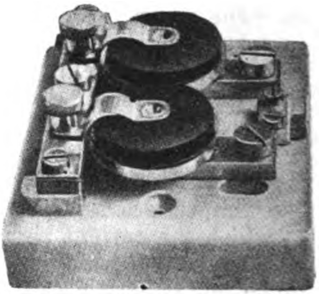

Fig. 441.—"C" protector with cover removed.

"D" Protector.

The "D" protector, seen in Figs. 442, 454, and 459, consists of two carbon plates 1 inch long by ½ inch wide, separated by a mica disc 3 to 5 mm. thick with three ⅛″ circular holes. In some forms the upper plate carries a small hole filled with metal having a low fusing point which will run and place the two plates in contact when a discharge occurs. This effectively earths the line, and protects the apparatus from damage. If a fuse is also in circuit this also is operated through the direct earth.

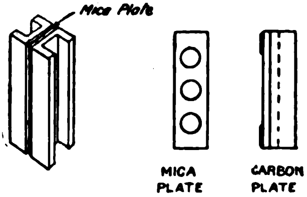

Fig. 442.—"D" protector.

A fitting consisting of two "D" protectors mounted similarly to the "C" protector is being used instead of "C" protectors on account of its cheapness and compactness.

"G" AND "H" PROTECTORS.

The G protector (Fig. 443), which is more efficient than the "C" or "D" forms, consists of a spark-gap between two carbon electrodes with serrated edges contained in a hermetically sealed glass tube, from which most of the air has been removed, thus creating a low vacuum. It is used in damp situations where the insulation of "C" protectors cannot be maintained, as, for example, in some pole test boxes.*

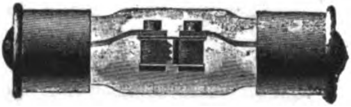

Fig. 443.—"G" protector.

The "H" type is similar, but is fitted with lugs, by which it may be connected up on ordinary instrument terminals. It is employed to protect the transformers used on telegraph superposed circuits, and a protector is placed across each winding, so that lightning discharges may be diverted from the coils.

These protectors, whilst having high insulation, are sufficiently sensitive to provide a path for currents due to contact with tramway trolley wires with a voltage of 500. The use of a low vacuum instead of air renders the difference of potential necessary to produce a spark far less than is necessary in air.

TABLET PROTECTOR.

The tablet protector is used on all Post Office submarine cable circuits at the junction of the cables and land lines. It comprises a plate protector, a 3-ampere glass tube fuse, and a combined inductance coil and reel protector. The latter consists of a coil of fine silk-covered platinum silver wire wound on a metallic earth-connected bobbin. The insulation of the wire forms the spark-gap between line and earth, but the more important function is to provide an inductive resistance immediately before the cable. The plate protector itself consists of two large oblong brass plates separated by a large mica disc with suitable holes to provide air gaps.

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* "Protection of transformers in pole test boxes," *P.O. Electrical Engineers' Journal*, Vol. IV. p. 341.

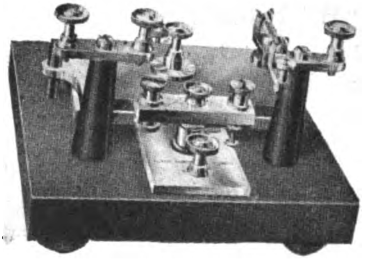

Fig. 444.—Tablet protector.

The land line is connected to the fuse and the cable to one end of the bobbin, whilst the junction of the fuse and bobbin is teed to the protector.

The arrangement is a most efficient one, but is, of course, more costly than any other types described.

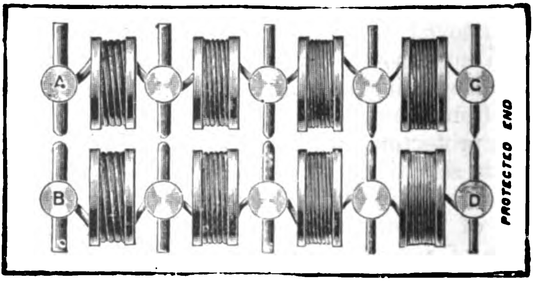

Fig. 445.—Principle of Lodge's lightning protector.

"F" Protector.

This type of protector is but little used. Its function is, however, to provide protection to a cable at the point where it joins an open line and it is fixed in the open air on the terminal pole. It consists of two concentric copper cylinders separated by a mica disc having 15 circular holes. The top of the under cylinder is closed by an ebonite disc, and the outer cylinder, the top end of which is copper, serves also as cover. The arrangement is mounted on a G. I. bolt, which makes contact with the inner cylinder and is earth connected, the cable being joined to the outer cylinder.

PROTECTORS OF SAUNDERS AND LODGE.

By way of conclusion to the descriptions of lightning protectors it will be interesting to consider two other types, viz. those of Saunders and Lodge. The former is in use upon many submarine cable circuits and consists of about 18 inches of fine platinum wire, kept stretched by a spring, along the axis of an earthed copper tube. The effect of a lightning discharge is to fuse the wire and so to break the circuit.

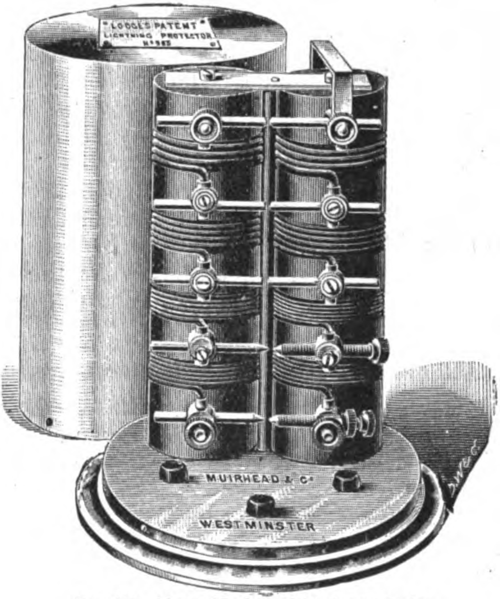

Fig. 446.—View of Lodge's lightning protector.

A view and the actual connections of one of Lodge's protectors are shown in Figs. 445 and 446. The instrument to be protected is connected between *C* and *D*, whilst the line and earth are joined to *A* and *B*. Each coil of wire is wound upon a groove in the ebonite pillars and the spark-gaps are made by approaching stout brass rods. When a heavy lightning discharge enters by the line, the major portion passes across the first gap while the remaining portions are filtered through the other gaps. The inductance of the coils plays a vitally important part in choking back the discharge. Since the coils are wound upon a non-metallic pillar, there is no possibility of the lightning discharge escaping other than through the air gaps; moreover for such discharges the impedance of coils so wound is far higher than with an iron core. The two final gaps are provided with screw adjustments so that the distance may be reduced to a minimum.*

In another form the Lodge and Saunders protectors are combined, and this appears, from a theoretical point of view, to be an ideal combination. The Lodge device absolutely secures against high potential, while the Saunders device ensures that the current shall not rise to danger-point.

POSITION OF PROTECTOR AND INDUCTANCE SPIRAL.

Protectors are fixed as near as possible to the point at which the wires enter the telegraph office. The earth connection from the protectors when there are more than six is made with a seven-eighteens, and when there are six or less with three-eighteens, bare stranded soft copper conductor, and the route followed by it on its way to earth is made as short and straight as possible, all sharp turns and bends being avoided to the uttermost extent. The wire should also be kept away from gas-pipes, and more especially when of lead, in order that the risk of "side-flashing" may be minimized. It will be obvious that a lightning discharge jumping from the earth wire to a leaden gas-pipe might readily produce a serious conflagration. In no circumstances should internal gas-pipes be near or be connected to the earth wire, and a connection between the service pipe on the street side is usually inadvisable. The street water-mains provide an excellent earth connection and are frequently used for this purpose (see page 174).

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* The full description of the experiments and tests which led to the design of the Lodge protector and the discussion upon the merits of the various forms is to be found in the *Journal of the Institution of Electrical Engineers*, Vol. XIX. p. 346 *et seq.* "On Lightning Guards for Telegraph Purposes," by O. J. Lodge.

The lead from outside is first taken straight to the protector and a spiral of about 10 turns of wire with a diameter of about $\frac{1}{4}$ to $\frac{3}{8}$ of an inch is formed in the lead to the instrument at the point at which it leaves the protector. The behaviour of this spiral resembles that of the coils of the Lodge protector, and since a spark of one millimetre length in air requires an E.M.F. of 3,000 volts, the importance of efficient protection can hardly be overestimated. It has been pointed out how great a resistance a relay or other telegraph instrument offers to a lightning discharge, but the statement needs to be qualified, since such a discharge jumps across the winding, and so avoids the self-induction. The small inductive spiral offers a very high resistance to an impulsive discharge, and there is no doubt that the addition is of the utmost importance in increasing the efficiency of the protection afforded.

The iron cases of the protectors should be earth-connected, so that lightning discharges side-flashing to them may be safely carried away. Similar remarks apply to the ironwork of test and cross-connection frames, and to the cable connection boxes described later, and, indeed, to iron troughings and the sheaths of lead cables.

It may perhaps be remarked that the connection of the line wire to the protector by joining the line to the instrument and then continuing it onwards to the protector is little better than omitting the protector entirely. If, in addition, the line wire is coiled spirally where it is connected to the protector, the inefficiency of the arrangement can scarcely be increased!

PART III. PROTECTION FROM POWER CIRCUITS.*

With the advent of electric tramways and electric light and power circuits worked from overhead conductors, there arose the necessity, first, for reducing the possibility of contacts between telegraph and telephone and power wires to a minimum; and secondly, to guard against damage to the apparatus and to avoid the risk of fire should such a contact occur. The first condition has been met by various methods of "guarding," and the second by the use of fuses and "heat coils" in the telephone and telegraph circuits within the area in which the power circuits are in use. It should be borne in mind that where electric tramways are concerned, the telegraph wires will always be *above* the trolley wires, whilst where electric light and power systems are involved, the telegraph wires may cross below as well as above the power circuits.

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* *Vide* "Protection from Power Circuits," by S. C. Bartholomew. A paper read before the Institution of P.O. Electrical Engineers, December 14, 1908.

GUARD WIRES FOR TRAMWAYS.

Where there is a single trolley wire, above which a route of telegraph wires cross, two wires, usually of No. 8 galvanized iron or seven strands of No. 16 wire, are erected at least 24 inches above the trolley wire. The two guard wires overlap the centre of the trolley wire by 8 inches upon either side, and both are efficiently earthed by connecting them via the support to earth by means of a copper wire.

The ideal arrangement consists in connecting the poles to the rails with copper bonds in just the same way that the various lengths of rail are bonded together to form the return conductor for the tramway currents. Where the guard wires exceed 200 yards in length, at least one earth connection per 200 yards should be made to the wires. The supports for the guard wires should be rigid, and at every support each guard wire should be securely bound in, or terminated.

The number of guard wires erected is in accordance with the gauge of the wires crossing, and the number of, and distances between, the parallel trolley wires. For instance, each trolley wire requires two guard wires when the distance between them is over four feet, whilst for a distance of from 16 to 48 inches three guard wires are used.*

The guard wires serve to prevent a broken telegraph line from falling directly on to the trolley wire. Where the wire happens to curl over and so to make contact with the trolley wire, it is also in contact with the earthed guard wire. Usually the current flowing to earth through the wire which forms the contact is sufficient to burn it up, or, with heavy gauge wires, is sufficient to blow the tramway section fuse. Another serious danger which the guard wires obviate is that a fallen telegraph wire in contact with the trolley wire would, of course, give electric shocks to any one who, without the aid of india-rubber gloves, was unwise enough to touch it. It may be said that efficiently maintained guard wires very greatly reduce the risks due to falling telegraph wires, but it must not be overlooked that the breakage of telegraph wires is a comparatively rare occurrence, especially when the wires are terminated upon either side of the crossing.

Guard wires are considered to be a great nuisance by the Bodies controlling tramway systems, and, wherever it is reasonably possible, covered telegraph wires are erected at tramway crossings so that guard wires may be dispensed with. The covering of this wire is of some interest. It should be explained that it is difficult to obtain a satisfactory insulated wire for use in the open. Rubber coverings are best, but the life of rubber when exposed to the atmosphere is short, and although when first erected the covering may be a perfect safeguard against contact with power wires, in the course of a few years the covering is a snare in that it gives a sense of false security. The special wire used at tramway and other power circuit crossings consists of bronze wire, 55 lbs. to the mile, insulated first with two lappings of manilla paper treated with linseed oil, over which is a spiral wrapping of cotton, and finally cotton braid, both of which are thoroughly impregnated with a mixture of litharge, linseed oil, and paraffin wax. The completed wire is also drawn through a bath of paraffin wax. The paper is the foundation of the insulation, the impregnated cotton and braid being primarily for the weather-proofing, but they have also good insulating properties. The insulation of this wire appears to improve with age, due to the oxidation of the mixture closing up the pores of the material. The wire has behaved well in districts where chemical fumes play havoc with ordinary bare and rubber-covered wires.

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* The full text of the Regulations and Explanatory Memorandum are given in the *Electrician* of February 20, 1903. The latest regulations differ in some respects from these. For instance, it is laid down that guard wires must be earthed at each end. This precaution was found necessary, as cases occurred where guard wires broke and the unearthed side made contact with the power wires. The latest Memorandum also shows more clearly when guarding is required for telegraph routes running parallel with the tramway track.

GUARDING ELECTRIC LIGHT AND POWER CIRCUITS.

The voltage employed on electric light and power circuits varies within wide limits. The systems are classified according to voltage by the Board of Trade, as follows—

Up to 250 volts . .	Low pressure.
Above 250 volts to 650 volts	Medium pressure.
„ 650 „ 3000 „	High pressure.
„ 3000 volts . .	Extra high pressure.

Guarding is not required by the Post Office where telegraphs are endangered by power circuits worked at pressures below 120 volts direct current and 60 volts alternating current. Fuses and heat coils are, however, fitted in the telegraph circuits endangered. It should be remarked, in passing, that shock from alternating current is more dangerous than from direct current—investigations have shown that, roughly, the severity of a shock from an alternating current of a certain voltage is the same as that from a direct current system of double the alternating current voltage.

With power systems between 120 volts and the limit of medium pressure (650 volts), the guarding arrangements vary according to whether the telegraphs or power circuits are uppermost, the number and formation of the power wires, and the separating distances between the power wires. The detailed arrangements are too lengthy to give here, but the following general description should suffice.

Where the telegraphs are uppermost, independent earthed guard wires may be erected above the power system, as in the case of tramways. There is a slight difference in that the overlap is governed by the distance between the highest and the lowest power wires, and does not keep the constant 8″ as with tramway systems.

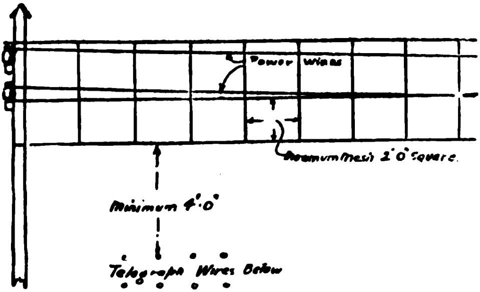

Fig. 447.—Side view of cradle guarding.

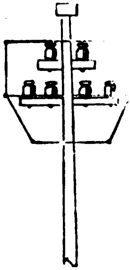

Fig. 448.—End-on view of cradle guarding.

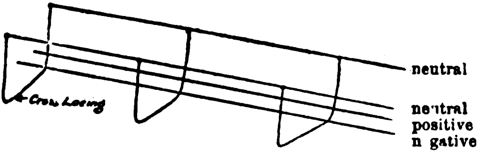

Fig. 449.—Sketch of cradling utilizing the neutral conductor.

It may vary between 4″ and 24″ according to the formation of the power wires.

Where a three-wire power system is concerned, with the neutral conductor earthed at the power station, the neutral conductor may consist of two wires arranged to take the place of guard wires. This method has advantages, in that, if arranged for when the power system is installed, the addition of telegraph crossings subsequently does not involve changes and consequent expense.

Where the power system is uppermost, the usual guarding may be cradling arrangements, which prevent the potential wires falling on the telegraph wires.

The cradling can be made with independent earthed wires, or by utilizing the earthed neutral conductor, if the system is three-wire. Figs. 447 to 449 indicate the arrangements.

As in the case of tramways, covered conductors for the telegraphs are erected where the routes and circuits are unimportant. Similar wire to that previously described is employed.

If covered conductors, supported by earthed suspending wires, are used on the power system, additional guarding is not required. The earthed suspending wire, in addition to acting as a safeguard in itself, ensures that the coverings of the power wires will be maintained in good condition by the owner of the power circuit, as, otherwise, current will be lost.

Where power systems are worked at high and extra high pressures, it is now the practice to ensure that contact between the telegraphs and such systems is rendered impossible by placing either the telegraph wires or the power wires underground at the danger points. As some of these systems are worked at pressures reaching 20,000 volts, the need for stringent precautions requires no emphasis.

For some years, however, various arrangements have been adopted to meet the difficulties which the power companies experienced in interpolating short lengths of underground in their open lines. Elaborate cradles were erected where the voltage did not exceed high pressure (3000 volts), and for extra high pressure systems a "joint pole" was the usual method of crossing. The "joint pole" is an H pole structure used for carrying both sets of plant at the crossing point. The power wires are uppermost, separated by a well-earthed metal platform from the telegraph wires crossing below. The routes of the wires must be at right angles at the crossing point, and the resistance of the platform to earth should not exceed 1^{ω}. Fig. 450 shows one of these structures.

These crossings usually occur on a public road, and, to

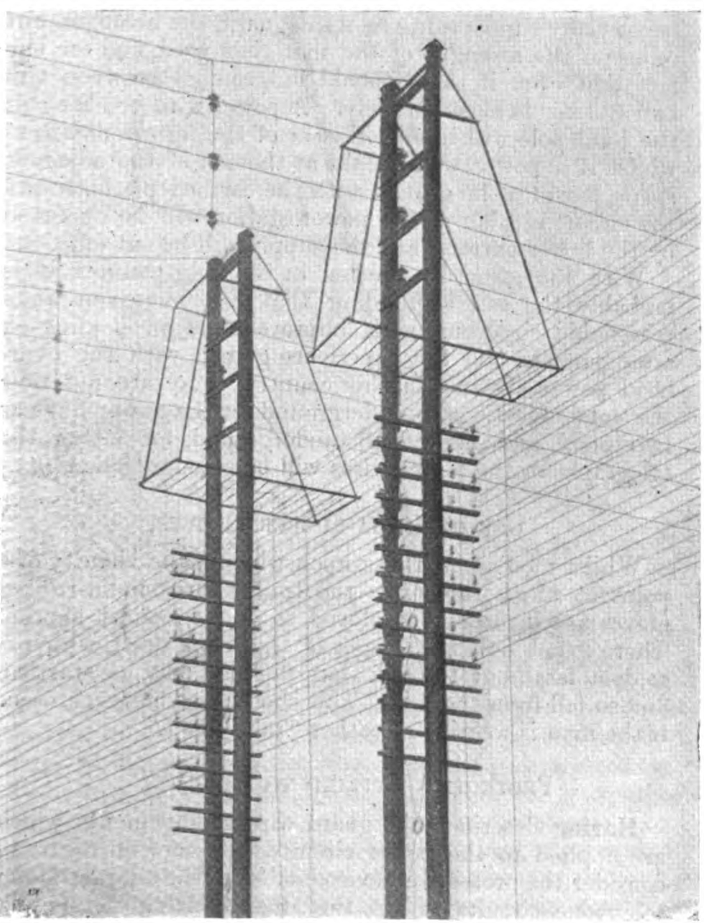

Fig. 450.—A pair of joint poles each carrying three power wires

meet the Board of Trade requirements for the protection of the public, the power wires crossing the road have to be specially supported. As a safeguard, the arrangement relies on the strength of the materials used, and on the fact that even if these should fail, contact between the two systems is most unlikely. A power wire breaking at the joint pole will be pulled clear of the telegraph wires; whilst if a power wire breaks at the end of the adjacent spans, it will make contact with the earthed platform and the circuit breaker at the power station will be operated by the heavy current, and the supply will be cut off.

With the structure erected in a stable manner, it is probably the safest guarding that can be given at a reasonable cost, but with improvements in leading-off arrangements, and the experience gained with the overhead power systems in this country, there are not now the same objections to underground for the power lines as heretofore, and, henceforth, underground for either the telegraphs or the power wires will be standard practice.

Use of India-rubber Gloves.

Whilst men are working upon wires in the vicinity of a point at which they cross the trolley wires, india-rubber gloves are invariably employed to guard against shocks. There is not only the danger of the shock itself, which is seldom fatal, but the risk that the man may be startled, and so fall from the pole. This should not, however, occur, if the man is wearing a leather "safety belt."

Protection applied to Circuits.

Having described the guard wire arrangements which are applied to the power circuits, it is now necessary to consider the protective devices added to the telegraph and telephone circuits within the affected area. Supposing that a contact between a power circuit and a telegraph wire occurs, the effect of these devices is (1) to protect the apparatus from damage, and (2) to prevent lines passing through the affected area from continued contact with the power wires. The first condition is fulfilled by the provision of a heat coil upon the line side of the apparatus, and the second by the use of fuses.

GLASS-TUBE FUSE.

The 3-ampere glass-tube fuse (Fig. 451) consists of a thin platinum wire 5 mils in diameter, contained within a glass tube two inches long, the ends of which are closed by two tinned brass caps cemented with shellac. The fuse wire is passed through two central holes in the caps and soldered, the function of the other holes being merely to allow for the expansion of the air which results when the fuse is "blown." The brass caps form the terminal connections, which make contact with the holding clips.

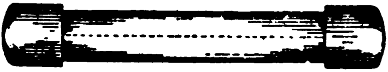

FIG. 451.—Glass-tube fuse.

HEAT COILS.

It is impracticable, owing to the exceptionally small gauge of wire needed, to provide a fuse which will be blown by a current much less than one ampere. Now, a current of far less than this amount, flowing through a relay or other telegraph instrument, would produce very serious damage, and it is quite possible that a fire might even be originated in this way. The heat generated by a current in a conductor or system of conductors is proportional to the square of the current, to the resistance of the conductors, and to the time during which the current is flowing. The temperature of the conductors depends upon the difference between the rate at which heat is generated by the current and the rate at which the heat is radiated. When the conductors are in a comparatively confined space, the temperature may rise sufficiently to produce disastrous results.

The "A" type of heat coil "strikes" when a current of 250 m.a. flows through it for a period of 30 seconds. Currents smaller than 250 m.a. may pass for an indefinite time, whilst a larger current operates the coil more quickly. A section of a heat coil and a view of its appearance are given in Figs. 452 and 453. A coil of fine wire is wound upon a small brass bobbin with fibre cheeks. One end of the coil is soldered to the bobbin, whilst the other end passes through to the grooved metal washer, which is carried by, but insulated from, the screwed extension of the bobbin. The left end of the bobbin is bored so as to receive the pin, which is secured in its position by a special type of solder having a very low fusing point. When a current of 250 m.a. passes for 30 seconds the heat generated is sufficient to melt the solder, and the pin is then pulled out by the action of a spring and the circuit disconnected. The resistance of the coil is about 25ω. A recent improvement in design has been effected, and a heat coil which strikes at 250 m.a., but having a resistance of only 15ω, has been introduced. It may be distinguished from the 25ω coil by its blue-coloured case.

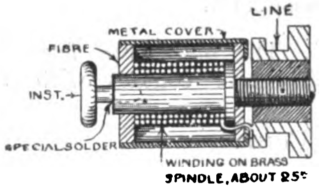

FIG. 452.—"A" form of heat coil drawn to about twice its full size.

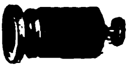

FIG. 453.—Heat coil (full size).

The heat coil already described strikes with 250 m.a. in 30 seconds, and it has been found that, upon high speed Wheatstone circuits of considerable capacity, these coils are operated by the working currents. In order to avoid this trouble heat coils with a striking point of 500 m.a. in 30 seconds are employed upon such circuits. These two types of heat coil "A" are distinguished by the colour of the case, which is red for 500 m.a., and black or blue for 250 m.a. coils.

There is another form of heat coil, used upon main distribution frames, which is known as the "B" type. It differs from the "A" form in that the heating of the fusible alloy causes the coil itself to slip down the projecting pin, upon which it is soldered, into the interior of the cover. The spring consequently presses the pin forward sufficiently to bring about the earthing of the line. The resistance of the coil is 30^{ω} with a striking point of 250 m.a., and $3{\cdot}8^{\omega}$ with a striking point of 500 m.a., the latter form being very extensively used in connection with the Common Battery telephone system.

COMBINED PROTECTOR, HEAT COIL, AND FUSE FITTING.

Where the number of circuits to be protected is very small, such as at sub, and other minor, offices, the heat coil, protector, and fuse, are mounted together upon one base. Such a fitting, suitable for two lines, is shown in Fig. 454. The base is of porcelain and the cover of tin, lined upon the interior with fireproof material. The protectors are of the "D" type, and fuses of the glass-tube pattern, already described, are employed. The heads of the heat-coil pins are placed within the slots of the two brass springs, which exert an outward pull upon the pins.

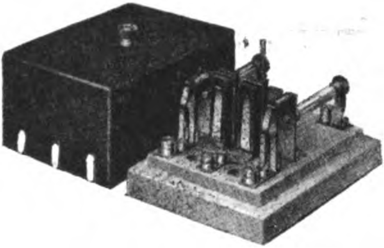

FIG. 454.—Combined protector heat coil and fuse fitting for two lines.

The general arrangement of a fuse, protector, and heat coil is indicated in Fig. 455, from which it will be observed that the line wire is connected to the fuse, and that the protector is placed at the junction of the heat coil and the fuse. In the later forms of the apparatus a second spring, held away from an earthed contact point by the spring operating the heat coil, is added. A current of 250 m.a., whilst leaving the fuse intact, operates the heat coil, so disconnecting the instrument and earthing the right-hand side of the fuse. Usually, the reduction in the resistance of the circuit increases the current sufficiently to blow the fuse and disconnect the line.

PRINCIPLES GOVERNING THE FITTING OF HEAT COILS AND FUSES.*

Where a route of through wires traverses a power area, fuses are inserted at the boundaries, whilst the offices upon each wire are protected by heat coils. These fuses are fixed upon specially designed fuse insulators (Fig. 457). The insulator is of the same general pattern as the P.O. terminal type, but the top is shaped to receive a pair of clips (Fig. 456) mounted on a plate, and a hole is provided for the connecting wire to each groove, the two sides of the line wire being terminated in the upper and lower grooves of the insulator. A black ambroin cap screws on to the top and serves to protect the fuse and clip from the action of the elements.

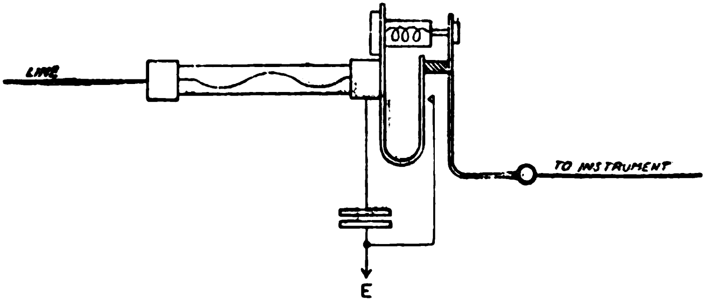

Fig. 455.—Principle and arrangement of combined fitting.

When a contact with a power wire occurs, the heat coil at the office is operated, and the earthing of the circuit blows the fuse at the boundary of the area, and so prevents the length of wire between that point and the office from remaining "live."

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* The trouble caused by lightning in blowing fuses has led to considerable simplification in the matter of fitting line fuses. Line fuses were frequently fixed at points not readily accessible, and serious interruptions of service occurred owing to the delay in replacing blown fuses. The practice has therefore been modified to the extent that fuses and heat coils are now placed only at terminal offices, line fuses being dispensed with. The previous practice which is described provided the best possible protection from power circuits, but its disabilities outweighed the additional safety obtained by having fuses in the line instead of at offices only.

The positions of the fuses are governed by the following rules, which may readily be deduced from the general principles already stated.

(1) In the case of a single crossing a fuse is fixed at any convenient point upon either side of the crossing.

(2) In a power area one fuse is fixed at the office (or at the junction with the underground) and one just beyond the boundary of the area.

(3) A wire passing through an office within a power area requires a fuse at each boundary, and two, either at the office or at the ends of the underground.

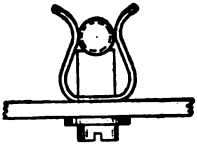

Fig. 456.—Side view of fuse and clip.

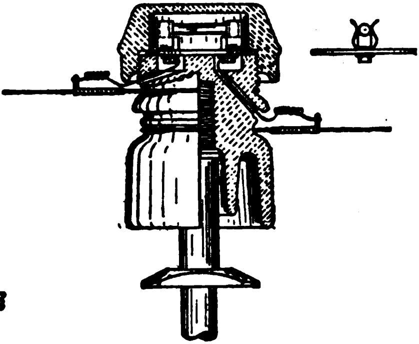

Fig. 457.—Fuse insulator.

(4) Through wires passing through a power area without entering an office require one fuse at each boundary.

(5) In the case of "leak" circuits one fuse is inserted in each wire of the main circuit, or in default one fuse at each office.

(6) The distance between two fuses must not exceed 50 miles, nor must the resistance of the line connecting them exceed 100$^{\omega}$.

A few typical cases may be considered by way of illustration. Consider a head office with a number of sub-offices served by open wires, all of which are within an area where electric trams are running. Each sub-office would be protected by a 2-line combined heat coil protector and fuse fitting of the type shown in Fig. 454. At an intermediate office both sides of the fitting would be needed, whilst at a terminal office only one fuse, heat coil, and protector, is required.

Had the wires from the sub-office entered the large office through a length of underground the fuses would be placed in the pole test box at the junction of the open and underground lines.

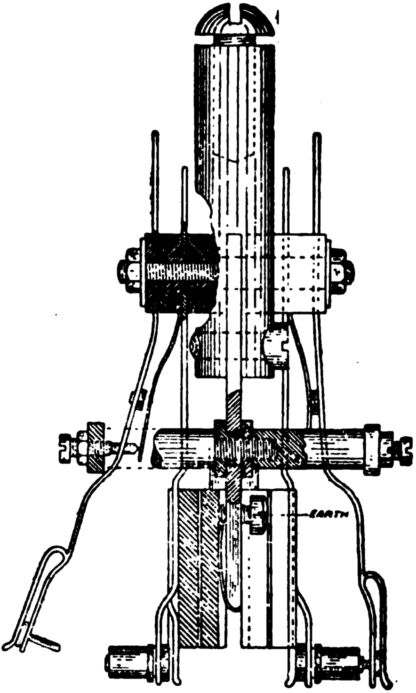

FIG. 458.—Heat coil and "D" protector strip.

Conditions 5 and 6 require the addition of a central fuse where the various electric tramway systems form a practically unbroken area of large dimensions. In such cases the 100$^{\omega}$ limit for the resistance between the fuses makes it reasonably certain that the fuse will be operated when a contact with the trolley circuit (voltage usually about 500) takes place.

HEAT COIL, PROTECTOR, AND FUSE FITTINGS.

A view of a strip of heat coils and "D" protectors, together with a section showing the precise arrangements of the various parts, is shown in Figs. 458 and 459. The strips are mounted in cast-iron boxes with iron covers, and are made in sizes to take 20, 40, 80 and 160 wires respectively. Fuses are also added.

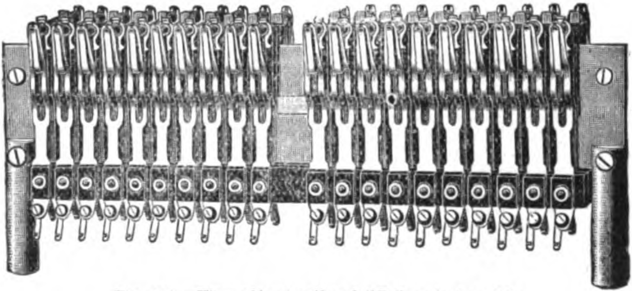

FIG. 459.—View of heat coil and "D" protector strip.

THE MAIN DISTRIBUTION FRAME.

The main distribution frame provides a testing point, a cross-connection field, and also serves to carry the heat coils, protectors, and fuses. The frame is built up of angle iron and is made in units each of which accommodates 480 wires. Fig. 460 is an end-on view of the frame, from which it will be seen that six fuse and six protector and heat coil fittings are arranged in vertical lines on opposite sides of the frame. Each unit of the frame consists of two such vertical rows arranged side by side. Each fuse fitting (Fig. 462) carries 40 fuses (20 on each side of the iron mounting plate). It will be observed that the fuses are staggered to facilitate removal when required. A protector and heat coil strip is shown in Fig. 461. The protectors are of the "D" type and the

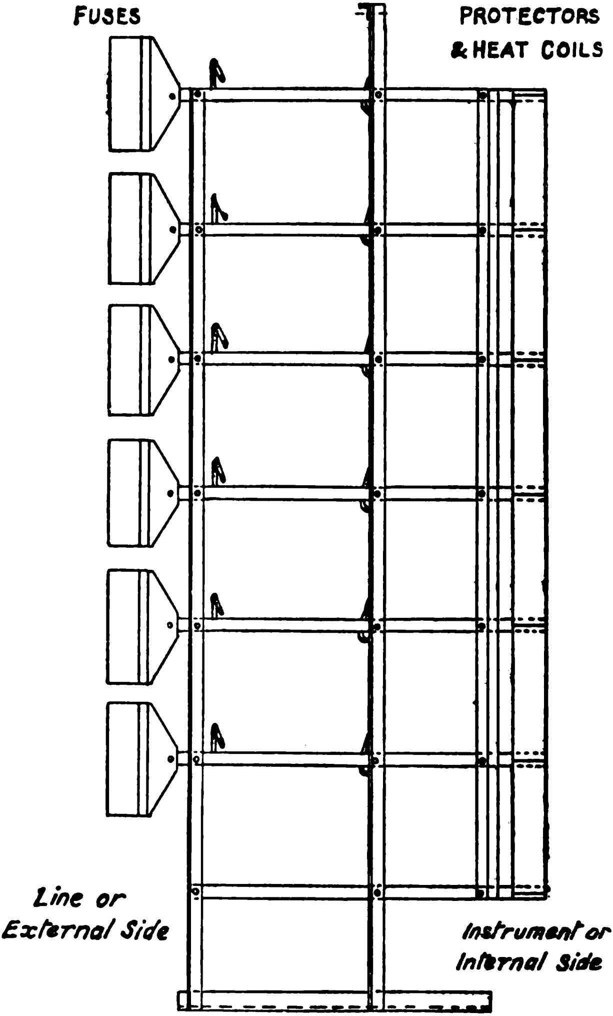

Fig 460 —Main distribution frame, end view.

heat coils of the "B" pattern (*q. v.*). The underground cables are terminated in cable order on one side of the fuses, and the cables to the test box are similarly connected to one side of the heat coil in cable order. The connections between the two sides of the frame are made with single wires having 12½ lb. enamelled copper wire covered with flame-proof insulation. It will be recognized that any circuit changes may be carried out without interference with the line or instrument cables by means of the cross connecting or "jumper" wires connecting the two sides of the frame. To preserve an orderly cross-connection field insulated rings are placed close to each fuse mounting and also in the centre of the frame (see Fig. 460).

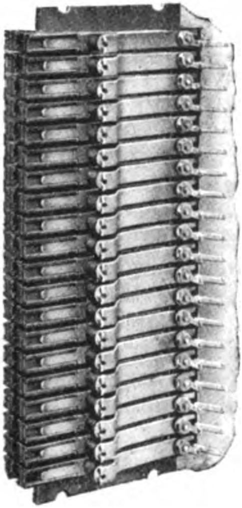

FIG. 461.—Strip of protectors and heat coils.

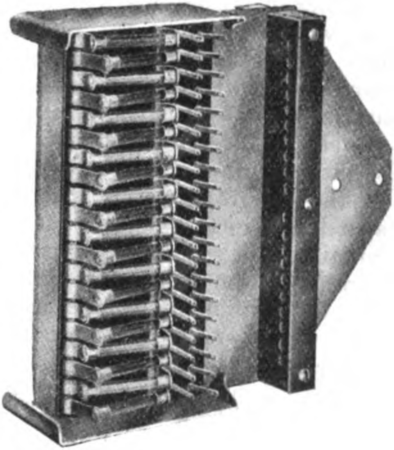

FIG. 462.—Fuse strip.

All cross-connecting wires pass through these rings, the principle adopted being to ensure that each individual wire passes through two, and only two, rings—thus ensuring an orderly method of running the jumper wires. In the case of telephone circuits connected to the frame, twin is used instead of single wire for cross connections.

Testing operations are effected by removing a pair of heat coils and inserting a horseshoe-shaped plug, which picks up the external and internal sides of the two wires. Suitable testing apparatus of the general form of that of Fig. 474 is provided in connection with these plugs.

PART IV.—POWER CIRCUIT INTERFERENCE WITH TELEGRAPHS.*

Electric tramways and railways using uninsulated rail returns for their currents have interfered with the working of telegraph circuits. The Board of Trade limit the voltage drop on the rails to 7 volts, but even with this limitation false signals may be given by the stray currents from the traction systems if the telegraph offices are favourably situated for the current to return to the power station via the telegraph wires. The trouble, if slight, can usually be cleared by increasing the resistance in the telegraph circuit by means of coils, and correspondingly increasing the battery power for working the circuit. The additional resistance reduces the foreign current in the telegraph circuit to a negligible amount, but necessitates, of course, additional battery power to produce the proper working current. Cases have occurred where it has been necessary to alter the traction system so as to reduce the stray currents.

The majority of electric tramway and railway systems in this country are worked with direct current, and such systems do not adversely affect telegraph circuits by induction. In some cases, however, railways are worked on what is known as the "single phase" system, in which an alternating current is employed. Extra high tension currents (6,600 volts) alternating at 25 periods per second are employed, the current being fed into an overhead contact wire and returning to the power station via the train and the uninsulated rails. This system of electric traction has serious inductive influence on telegraph circuits running parallel to the track, high voltages being induced which cause continuous chattering of the relays. In severe cases it is not possible to bias out the effects, and recourse has to be made to expedients for reducing or shunting the disturbing currents.

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* Vide *Power Circuit Interference with Telegraphs and Telephones*, by S. C. Bartholomew, a paper read before the Institution of P.O. Electrical Engineers, December 23, 1914.

As the induced voltages may be very high, the addition of considerable ordinary resistance would be required to cut down the current. Inductive resistances suitable for alternating current are more effective, but where the induced voltages are so great these palliatives are not practicable. The alternative to these brutal methods is the provision of a shunt to the apparatus to take off the induced currents.

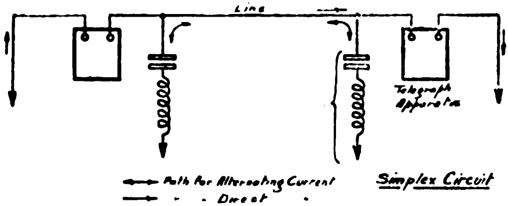

Fig. 463.—Application of resonant shunts to a simplex circuit.

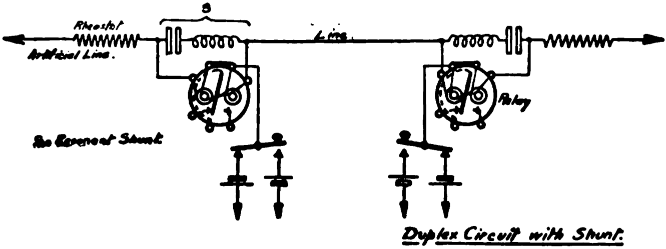

Fig. 464.—Application of resonant shunts to a duplex circuit.

Figs. 463 and 464 respectively show the application of such a shunt to simplex and duplex circuits. The method is based on the fact that the current has a definite periodicity or number of alternations per second, and that an alternating current will flow through a circuit through which a direct current will not pass, The power circuit inducing the current alternates at 25 times per second and the induced current will also alternate at the same rate. A direct current will not flow through a condenser, whilst an alternating current will flow in a circuit composed of a resistance and a capacity in the form of a condenser, and if the resistance is inductive and the inductance bears a certain relationship to the capacity of the condenser, the resistance of the circuit will be that of the resistance of the inductance only. This state of affairs exists when there is what is called a resonant circuit, which is expressed in its simplest form in the following formula—

$$n = \frac{1}{2\pi\sqrt{KL}}$$

where n = Alternations per second of the current
K = Capacity in farads
L = Inductance in henries
$\pi = 3{\cdot}1416$

If, for instance, the frequency of the alternating current is 25 per second, then, if K and L are of such values that $\frac{1}{2\pi\sqrt{KL}}$ equals 25, the maximum current will flow through the shunt circuit. Any other value of K × L will result in a smaller current passing through the shunt with a given induced voltage. Now K × L, with K in microfarads, is a constant figure of roughly 40 which can be obtained in numberless ways. For instance, it may consist of $K = 8$ microfarads and $L = 5$ henries, or $K = 5$ microfarads and $L = 8$ henries. There are disadvantages with high capacity or high inductance. If a high capacity is employed it will seriously reduce the strength of signals on certain types of circuits, whilst a high inductance involves a high resistance to produce the inductance unless considerable iron is used with the coil, and high resistance will defeat the object of the shunt. Again, if iron is used, then the inductance will vary with the current passing and the shunt will cease to be resonant at all values of current. An air coil inductance is to be preferred on this account, but the resistance would have to be high to produce a reasonable inductance figure. With all these drawbacks, however, it is possible by means of this type of shunt to make circuits workable which would otherwise be unfit for use. Its use is limited to circuits worked at hand speed—as with automatic working alternating current conditions are produced and at certain speeds the signals are distorted owing to the shunt coming into operation and providing a path for the working current. Wheatstone running at about 65 words per minute corresponds to 25 alternations per second, and at that speed and multiples thereof the signals on the slips become mutilated and unreadable if a shunt is on the circuit.

A simpler remedy is sometimes effective with simplex circuits. Figure 465 illustrates the arrangements. It will be seen that the line wire is taken through a transformer and that one coil only of the relay is used for the telegraph working—the other coil being in the secondary circuit of the transformer. The current produced in the secondary circuit of the transformer nullifies or reduces the effect of the induced current in the main current at the relay.

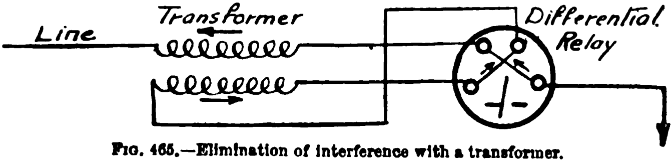

FIG. 465.—Elimination of interference with a transformer.

There are other variations and refinements of these two methods which cannot be gone into here.

It should not be overlooked that these devices are palliatives only—the efficiency of the circuits is reduced by their presence, and the only really satisfactory remedy is to be found in removing the trouble at its source, which is again a matter outside the scope of this book.

PART V.—PRECAUTIONS AGAINST FIRE.*

Although the modern post office building with its concreted floors supported by steel joists contains the minimum amount of inflammable material and is practically fire proof, immunity from fire risk ceases when the various fittings, mainly of wood, are introduced. One of the principal sources of danger in the past consisted in the use of large vertical wooden chases, containing gutta percha-covered wires, passing through the various floors. This has now given place to lead-covered cables carried on iron cable-racks, in iron casing, or in iron pipes, and flame-proof wire is used for joining up apparatus. Where cables pass through floors the unoccupied space in the chute is packed with asbestos carried by iron plates at each floor-level so that flames may not, in the event of fire, be carried from floor to floor viâ the cable chutes.

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* Vide *Precautions Against Fire*, by A. J. Stubbs, a paper read before the Institution of P.O. Electrical Engineers, January 8, 1912.

The complete destruction of the building by fire may be highly improbable, but the consequences to the community would be of so serious a character that the possibility must be considered. Further, in such an event, it is probable that for some time afterwards it would not be safe to approach the building owing to falling débris and the possible instability of the outer walls. Every wire in each cable entering the building is therefore numbered at the first joint from the post office, and thus every wire is identified at a point clear of danger. The first jointing chambers on each route are connected by pipes, so that, in the event of fire, through wires may be joined across and the terminated wires taken to the temporary telegraph office. Usually, arrangements are made for premises to be available, such as, for example, a part of the town hall or other municipal or State building, and this is connected by pipes to the nearest jointing-chamber. For example, suppose that four routes enter the post office from the N., S., E. and W., and that the premises available for the temporary office are near the S. jointing-chamber. Pipes connect the N. and W., W. and S., S. and E., and E. and N. jointing-chambers and the S. jointing-chamber and the temporary premises. It will be recognized that the pipes form a ring round the office and that the through wires can, with the aid of suitable cables, be joined through and the terminated wires concentrated and taken from the S. jointing-chamber to the temporary office. Battery power would have to be provided by dry cells, but the central battery working could no doubt be arranged in many cases from other offices.

The open wires which enter the building via the standard are usually few in number, and these are picked by aërial cables at the first pole or standard from the post office—these fixtures being adequately stayed withstand the stresses caused by the collapse of all the wires on the standard.

OFFICE WIRING

It may be well here to summarize in general terms the details of the scheme of wiring a large office. Each paper core cable is taken to a point three or four yards from the main distribution frame, where it is jointed to a lead-covered silk and cotton cable which is laced out on the frame (see page 904). The lines are cross-connected with single flame-proof wire to the instrument side of the frame whence 127-wire lead-covered silk and cotton cables are carried to the test board. Thence, instrument 5- and 7-wire lead-covered silk and cotton cables are carried in iron troughing and are terminated on 7-tag connection strips on each instrument table; the connections to the instruments and the connections of each set are made with flame-proof wire. The battery connections are made as described in Chapter XVIII, and here again the fire risk is reduced to a minimum.

The circuits on the standard are connected to lead-covered cables at the pothead insulators and the cables carried to the main frame.

CHAPTER XXI

TELEGRAPH TESTING AND THE FORMATION OF SPECIAL CIRCUITS.

THE efficiency of a telegraph system is dependent upon the efficiency of the maintenance of the lines and upon the prompt discovery and removal of faults and minor defects. The latter is a matter of importance since, if slight defects are allowed to accumulate on a line prolonged partial or total stoppage occurs during wet weather owing to the difficulty and time taken to trace the several minor defects.

The condition of the various circuits is verified each morning by a test of actual working of the circuit or circuits in charge of each telegraphist.* Any difficulty or defect is reported to the test clerk, who proceeds to discover the nature of the fault, and then to ascertain its position. For this purpose all long circuits are led through test boxes placed in some or all of the post offices *en route*. Where the sections of line are unduly long, there are pole test boxes or poles carrying dummy fuses. The guiding principle in making these arrangements is to secure the speedy removal of faults, and therefore it is essential that the distances to be traversed by the lineman in search of a fault shall be such that the fault can be located and removed during the first day on which it manifests itself. In some cases, a lineman starts from each end of the faulty section, and the two men meet at a prearranged point—usually a pole test box or dummy fuse pole. In the event of heavy gales—and an approaching gale generally gives adequate warning—it is usual to send men through all the main lines without waiting for specific advices of faults.

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* Formerly, every important circuit was, each morning, subjected to the Eden morning test (fully described in the earlier editions of this work) to ascertain its working condition.

In order to improve the "transmission" or speaking efficiency of long-distance trunk telephone circuits, a definite effort has been made to eliminate these frequent leading-in points. Such circuits are now led in to only one office per 100 miles, and the position of a fault in a section of this length is ascertained by means of a Varley test (*q. v.*).

The telegraph service, as a whole, is divided into two divisions—the commercial or traffic side and the engineering side. The former controls the actual transmission of messages and in addition makes all morning and localization tests, reporting the existence and locality of faults to the engineering department, one of the functions of which is to construct and maintain the lines and apparatus. In the engineering department, the linemen are responsible for the maintenance of the lines and apparatus and for the removal of faults.

EFFECTS OF LOSS OF INSULATION.

In the case of a perfectly insulated circuit the current sent out and the current received at the distant end are each equal to the total E.M.F. acting in the circuit divided by its total resistance. It can be shown that a uniformly insulated circuit may be represented by a perfectly insulated circuit having the same conductor resistance, but with a single earth fault, termed the resultant fault, equal in resistance to the insulation resistance (*q. v.*) at the centre of the circuit. For example, an open line 100 miles long would have about 3000 insulators upon it. Assuming that the resistance of each insulator was 10 megohms and that the resistance of the circuit was 1000^{ω}, then this line is equivalent to a line having a conductor resistance of 1000^{ω} perfectly insulated save for a fault at its centre (500^{ω} from each end) equal to

$\frac{10{,}000{,}000}{3000} = 3{,}333^{\omega}$. Where the insulation is not unifor the position of this resultant fault will lie away from th centre of the circuit.

The effect of an earth fault on a circuit is to increas the current sent out (observed on the galvanometer) an

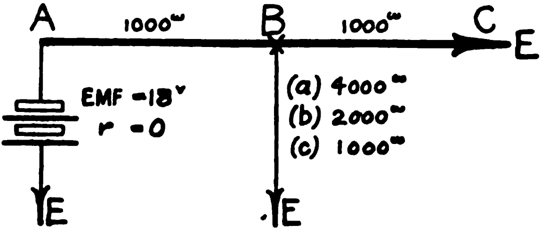

FIG. 466.—Circuit with fault at the centre.

to reduce the current received. This will readily be apparent by considering the case illustrated in Fig. 466. When the circuit is perfectly insulated the current sent out and that received is 9 m.a. With the resistance of the fault resistances shown, the conditions are as under—

Resistance of fault.	Current sent out.	Current received.
Infinity	9 m.a.	9 m.a.
4000ω*	10 m.a.	8 m.a.
2000ω	10·8 m.a.	7·2 m.a.
1000ω	12 m.a.	6 m.a.
0ω *i. e.* full earth.	18 m.a.	0

* Resistance of circuit = 1000ω + joint resistance of BC, and the fault

$$= 1000 + \frac{1000 \times 4000}{1000 + 4000} = 1800^{\omega}$$

$$\text{Sent current} = \frac{18^{v}}{1800^{\omega}} = 10 \text{ m.a.}$$

$$\text{Received current} = \frac{4}{5} \text{ of } 10 \text{ m.a.} = 8 \text{ m.a.}$$

Loss (*i. e.* current through fault) = 2 m.a.

It is interesting to notice that when the resultant fault is at the centre of the circuit the current sent out is increased by precisely the amount the received current is reduced as compared with the current sent or received if the circuit is perfectly insulated.

The effect of a fault of given resistance upon the working of a circuit is influenced very considerably by its position. The ill effects of an earth fault are greatest when it is at the centre of the circuit and least when at either end.* Indeed, a fault which at the centre of the circuit would render working impossible may, if situated at or near either the sending or receiving end, produce comparatively little effect.

DEFINITION OF INSULATION AND CONDUCTOR RESISTANCE.

The true insulation resistance of a line is the joint resistance of all the paths along which a current can escape or leak to earth. In the case of an open line it is the joint resistance of all the insulators to the passage of current over their surfaces. The true conductor resistance of a line is the resistance of the line wire itself. The true insulation resistance and the true conductor resistance are entirely separate entities, but in most tests the "apparent insulation resistance" and "apparent conductor resistance" are measured, and in these cases the two measurements are interdependent; for, the apparent insulation resistance is the true insulation resistance modified by the value of the true conductor resistance, and, similarly, the apparent conductor resistance is modified by the insulation resistance. The apparent insulation

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* Taking the conditions of Fig. 466, but calling the resistance of the section AB up to the fault (including the battery resistance) R, and that of BC away from the fault (including the receiving apparatus) R_1, and the fault f ohms, respectively, then the current received C due to E volts is—

$$C = \frac{Ef}{RR_1 + f(R + R_1)}$$

In this expression RR_1 is the only factor which depends upon the position of f in the circuit, and has its maximum value when $R = R_1$ and is least when either R or R_1 is least.

resistance is always higher, and the apparent conductor resistance is lower, than their true values.

A numerical example in which, for simplicity, the values chosen are widely different from any occurring in practice will best serve to illustrate the principles involved. The line (Fig. 467) is supported by four insulators *A*, *B*, *C*, and *D*, the insulation resistance of each of which is 100$^{\omega}$, and the resistance of each of the three spans of line wire between them is 40$^{\omega}$. The resistance of the line wire itself is 120$^{\omega}$, and this is the true conductor resistance of the line. If now a Wheatstone Bridge is connected between *A* and earth with *D* put to earth, a balance will be obtained with 45$^{\omega}$, and this value is the apparent conductor resistance.*

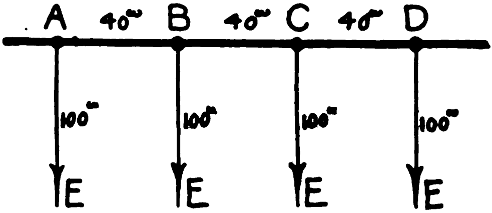

FIG. 467.—A circuit having a conductor resistance of 120$^{\omega}$ and an insulation resistance of 25$^{\omega}$.

Similarly, the true insulation resistance is the joint resistance of the four 100$^{\omega}$ leakage paths and is equal to 25$^{\omega}$. But, when *D* is insulated and the apparent insulation is measured with a Wheatstone Bridge connected between *A* and earth a balance is obtained at 47$^{\omega}$.†

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* *D* being earthed the last insulator is short-circuited. The resistance from *C* is $\frac{40 \times 100}{40 + 100} = 28{\cdot}6^{\omega}$; from *B* (adding 40$^{\omega}$ *B* to *C*) is $\frac{68{\cdot}6 \times 100}{68{\cdot}6 + 100} = 40{\cdot}7^{\omega}$; from *A* (adding 40$^{\omega}$ *A* to *B*) is $\frac{80{\cdot}7 \times 100}{80{\cdot}7 + 100} = 45^{\omega}$ approx.

† Resistance *D* to earth is 100$^{\omega}$; from $C = \frac{140 \times 100}{140 + 100} = 58{\cdot}3^{\omega}$; from $B = \frac{98{\cdot}3 \times 100}{98{\cdot}3 + 100} = 49{\cdot}6^{\omega}$; from $A = \frac{89{\cdot}6 \times 100}{89{\cdot}6 + 100} = 47^{\omega}$ approx.

It will therefore be recognized that, in measuring the insulation and conductor resistance by a Wheatstone Bridge or by a Megger, the values obtained are true values only when the insulation resistance is much higher than the conductor resistance.*

INSULATION RESISTANCE PER MILE.

In order to compare the condition of the insulation on circuits of different length it is necessary to obtain the per mileage insulation resistance. Upon a long circuit there are more insulators than on a short one and therefore more paths of leakage. Assuming that the insulators in the two cases have equal resistances, the longer circuit will have a lower insulation resistance. Hence:—

Insulation per mile = Total insulation × Mileage.

For example, if the total insulation of a circuit 83 miles long is 30,000$^{\omega}$, the insulation per mile is 2,490,000$^{\omega}$, or approximately 2·5 megohms. The only case in which this rule does not accurately apply is when the insulation resistance is abnormally low or the conductor resistance is abnormally high. In this case the result obtained by multiplying the total insulation by the mileage is too high. Generally speaking the total insulation resistance, save upon very long circuits, is considerably higher than the

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* The true conductor resistance R_t of a uniformly insulated line having an apparent insulation I and apparent conductor resistance of R ohms is:—

$$R_t = \frac{\sqrt{IR}}{2} \cdot \log_e \frac{\sqrt{I} + \sqrt{R}}{\sqrt{I} - \sqrt{R}}$$

The true insulation is:—

$$I_t = \frac{2\sqrt{IR}}{\log_e \dfrac{\sqrt{I} + \sqrt{R}}{\sqrt{I} - \sqrt{R}}}$$

If the insulation resistance is at least 5 times the conductor resistance the following formulæ are correct to 1 %:—

$$R_t = R\left(1 + \frac{R}{3I}\right) \text{ and } I_t = I - \frac{R}{3}$$

(Chapter XXVII, Kempe's *Electrical Testing*, 6th edition.)

conductor resistance, and in that case the rule given is sufficiently accurate for all practical purposes.*

When two or more circuits are connected together, either by extension or by forking, the total insulation of the combination is the joint resistance of their separate insulation resistances. The conductor resistance may generally be ignored, and therefore the laws explained in detail on pages 48 and 49 may be applied.

In practice it is often necessary to make insulation tests to successive points on a circuit in order to determine which section is defective.

Example.—A circuit 50 miles long has a total insulation of 25,000$^{\omega}$. Tested to an intermediate point 20 miles distant its total insulation is 40,000$^{\omega}$. What are the per-mileage values of the insulation resistances of the sections?

Whole circuit, insulation per mile $= 25{,}000 \times 50$ $= 1{\cdot}25$ megohm.

Insulation per mile of first section $= 40{,}000 \times 20$ $= {\cdot}8$ megohm.

Total insulation of distant section $$= \frac{1}{\frac{1}{25000} - \frac{1}{40000}}$$
$$= 66{,}667^{\omega}$$

Insulation per mile of distant section $= 66{,}667 \times 30$ $= 2$ megohms.

In practice it is seldom required to know the true value of the insulation with very great accuracy, and in most cases a result correct to 10 %, or even 20 %, will suffice.

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* The true insulation resistance per mile i is the apparent total insulation I multiplied by the ratio of the apparent conductor resistance R to the true conductor resistance per mile r:—

$$i = I \times \frac{R}{r}$$

Example.—The measured or apparent resistance of a circuit 200 miles long having a conductor resistance of 12$^{\omega}$ per mile has an apparent total insulation resistance of 2500$^{\omega}$ and an apparent conductor resistance of 1200$^{\omega}$.

By ordinary rule, $i = 2500^{\omega} \times 200 = {\cdot}5$ megohm

By corrected rule, $i = 2500^{\omega} \times \frac{1200}{12} = {\cdot}25$ megohm

(*Vide* Kempe's *Electrical Testing*, pp. 541, 542.)

The per mileage value of the insulation resistance enables the condition of various circuits to be compared directly. In the case of a route of a dozen wires, the fact that a lower insulation is obtained upon a particular circuit indicates the presence of a minor defect, and the cause is then ascertained by examining the line. Again, lines between the same two points, but following different routes, may be very closely compared, since the climatic conditions are the same, and any considerable difference in the values obtained indicates that attention is required. The careful scrutiny of the results of the morning tests is a work of very great importance, and by investigating and remedying every abnormality as it arises, the condition of the circuits can be brought to the highest pitch of perfection.

Again, the condition of wires maintained by the different administrations may be compared.

PART I.—THE MORNING TEST.

Minor defects which separately may have little or no effect upon the working of a circuit become serious when allowed to accumulate, and their ill-effects increase with the length of the circuit. In order to avoid this periodical tests are made on all circuits over fifty miles long, and on circuits under fifty miles long when there are groups of five or more circuits and the offices between which they run open before 8 a.m. On telephone trunk circuits one test for insulation resistance and one test for conductor resistance are made between 7 a.m. and 8 a.m. once per month. On telegraph circuits one insulation test is made per week, save one week in every four, when a conductor resistance test is taken instead. Loops are formed whenever practicable, thus testing two wires at each operation.

The tests are made with a 250^{v} megger (*q.v.*) reading from 1000^{ω} to 20 megohms. With the aid of tables the insulation resistance per mile is entered on forms sent to the engineering department, where the results are scrutinized and steps taken to locate and remove any defects revealed.

In the case of very large offices a motor-driven megger mounted on a stand provided with wheels (after the fashion of a refreshment stand) is used to save the labour of turning the handle, and it has been found that one insulation resistance test per 5 seconds can be made.

The bridge megger is also used for conductor resistance, but a D rheostat, to which are added four extra plug coils (1^{ω}, 2^{ω}, 3^{ω}, 4^{ω}), replaces the relatively costly dial resistance box. With the aid of the 10^{ω}, 20^{ω}, and 4000^{ω} coils, it will be found that any resistance from 1^{ω} to $8{,}440^{\omega}$ may be obtained by gradations of 1^{ω}. The value of the periodical conductor resistance tests is to show up any cases of loose or defective connections.

The various tests are at scheduled times, so that the requisite loops, earths, or disconnections are, as a matter of routine, made at the offices to which the tests are taken. It has previously been pointed out that looping strips are provided for this purpose—upon boxes of the switch-spring type.

WORKING AND MAINTENANCE STANDARDS.

Whenever the total insulation of a circuit falls below the conductor resistance, the working speed of the circuit is reduced. In the case of short lines, the insulation may fall to an extremely low value before any trouble results, since the conductor resistance of the circuit is low, and the theoretical maximum working speed far in excess of the possible working speed, as limited by that of the apparatus used. For example, a 400 lb. iron wire circuit 50 miles long has a conductor resistance of 666^{ω}, and therefore the insulation might fall to ·033 megohm per mile. With a circuit 200 miles long the conductor resistance is 2664^{ω}, and to have a total insulation resistance of 2664^{ω} the insulation resistance per mile must be ·53 megohm. If the length is 400 miles the insulation per mile required is 2·13 megohms—a value which cannot be obtained during wet weather. The remedy is, of course, to use a wire of lower conductor resistance. The point to be noticed is that the longer the circuit the higher is the character of the insulation needed—in fact, the degree of insulation required varies directly as the square of the length of the circuit. It may again be pointed out that an insulation resistance in excess of the value given by this rule does not reduce the working speed.

Opposite each wire upon the test sheet is given the value of the insulation resistance per mile, corresponding to a total insulation equal to the conductor resistance. This is termed the "working standard" of the circuit. Where a route of wires contains both long and short lines, the whole of the wires are, of course, maintained at the values required upon the longest circuits. The minimum standard of insulation for open lines, known as the "maintenance standard," is $\frac{1}{8}$ megohm per mile, but, as has been shown, this value is inadequate to the needs of long circuits, and therefore the condition of any circuit falling below either the working or the maintenance standard is unsatisfactory.

PART II.—FAULT LOCALIZATION.

When a wire is reported faulty by the telegraphist in charge of the circuit, the test clerk at once proceeds to localize the position of the fault between the successive offices *en route* in the manner subsequently described ; but, before dealing with the line itself, makes quite certain that the fault is not in the apparatus or the leads from the instrument to the test box. This applies to every class of fault.

A book, in which every wire is entered together with the names and stations of the officers responsible for the good working of each length of the circuit, is kept near the test box at each testing office. When the fault has been localized this record is consulted and the officers responsible for the good working of the circuit are advised by service message.

VARIOUS TYPES OF FAULT.

Faults may be divided into three classes, viz. earths, disconnections, and contacts. In each of these classes the faults differ in degree, and the terms full and partial are used respectively to describe the very pronounced and the slight faults, in the case of earths and contacts. The disconnection faults range from a total disconnection down to a partial disconnection or even a "loss of conductance," which means simply a few ohms increased resistance due to a defective connection or to an unsoldered, or "dry," joint as it is termed.

A fault may be in continuous existence or it may only appear at intervals. The latter class of fault is indicated by prefixing the word "intermittent" to the description of the fault. For instance, the terms "intermittent contact" or "tapping contact" means a contact which only occurs at intervals.

Localization tests are made with the test box galvanometer and its accompanying switch, described later.

The name of every office is abbreviated by allotting codes consisting of either two or three letters; for instance, *TS*, *GW*, *BE*, and *SSZ* denote respectively London, Glasgow, Belfast, and Hanley. Where more than one circuit is provided between the same pair of terminal offices the circuits are distinguished by numbering from 1 upwards. For instance, $TS\text{-}GW_2$ denotes the second circuit between London and Glasgow. A similar procedure has been adopted in the case of the imaginary No. 3 circuit between *A* and *F* which passes through *B*, *C*, *D*, and *E* *en route*.

EARTHS.

In order to localize an earth fault the line is successively disconnected at the various testing points, and it is then ascertained up to which point the circuit is perfect and beyond which point it is defective. For this purpose an earthed battery and galvanometer are joined to the wire as shown in Fig. 468. The wire is first disconnected at *F*, and the degree of the fault judged. Where the fault is of a very slight character its resistance is measured with the megger and is stated.

Leaving the wire disconnected at *F*, *E* is next requested to "dis. $A\text{-}F_3$." Upon receipt of this reply from *E* ("$A\text{-}F_3$ dis."), the wire is again tested by applying the earthed battery and galvanometer. In the present case the galvanometer is deflected, thus indicating that the fault exists between *A* and *E*. *D* is now requested to disconnect the circuit, and upon again testing the earth fault has disappeared. In other words the circuit is clear *A* to *D*, but faulty *A* to *E*, therefore the fault is between *D* and *E*.

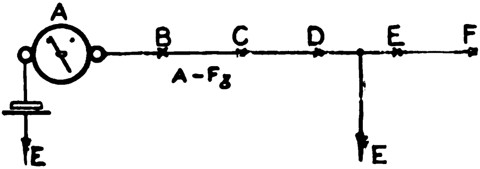


FIG. 468.—Localising an earth fault.

In the case of earth faults it is advisable to have the circuit successively disconnected from the terminal towards the testing station, since there is then no need to await replies that the circuit has been joined through by the various offices.

DISCONNECTIONS.

The various offices *en route* are successively requested to earth the wire and the earthed battery and galvanometer applied as in the case of earthed faults. In the present instance the presence of a deflection proves the continuity

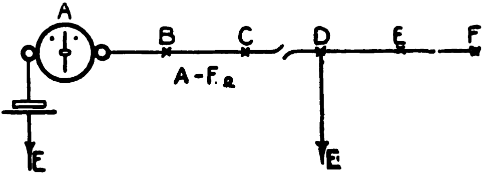


FIG. 469.—Localising a disconnection.

of the circuit between the two testing points, whilst the absence of a deflection denotes the presence of a disconnection in the section under test.

A central office may be asked to earth the wire so as to reduce the number of tests required.

Care must be taken not to make a second test until it is known that the first office has taken off his earth.

CONTACTS.

It should first be ascertained that the contact is not in the leads from the instrument to the test box. If such were the case the instruments would, of course, affect each other when both wires were disconnected at the test box. In large offices, where the instruments are beyond view from the test box, the instrument side should be tested in the same way as the line.

To test for a contact an earthed battery is connected to one line and an earthed galvanometer to the other. If the two wires are in contact the galvanometer is deflected. A battery and galvanometer joined in series (*i. e.* without an earth connection) with the lines is not satisfactory, for the reason that an earth fault upon each of the lines would give the same result as a contact and a wrong locality could very easily be given. The condition is illustrated in Fig. 470, where a wire going due west would be found to be in contact with one going due east, whereas two earth faults only exist. If two such wires were found to be in contact the fault could only be in the leads from the test box to the two routes, or possibly the wires might travel together in a common direction for a short distance, thus the length in which such a fault could occur would be well known to engineering officers. The addition of the earth connection between the galvanometer and the battery, as in Fig. 471, ensures that a deflection shall result only when the two wires under test are in contact.

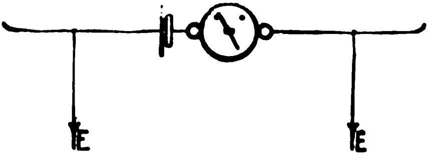


FIG. 470.—Illustrates necessity for earth connection when testing for contact.

Either of the two wires may be worked by disconnecting the other, and if it were decided to work A-K_1, then H would be advised to put this through, and C-M_2 would be left disconnected at the box or disconnected at D and E.

If a spare line between *D* and *E* is available a cross could be made and both circuits worked.

It is the practice periodically to test all faulty circuits to see if the fault has been removed, thus ensuring that the wires shall not needlessly remain idle.

It will be seen that localization tests are of an extremely simple character, but the utmost care should be taken. A mis-test, *i.e.* the reporting of a fault to exist in a wrong section, entails the examination of that section by the lineman, and it may not be found out that a mistake has been made until it is too late to get the fault removed upon the same day. Again, where a large number of tests are being made, the work must be done systematically, and attention is directed to the importance of receiving replies that particular operations have been performed before proceeding further with the tests. Moreover, a considerable local knowledge of the routes taken by the various circuits is highly desirable, as it tends to expedite the process of testing and advising the existence and locality of faults.

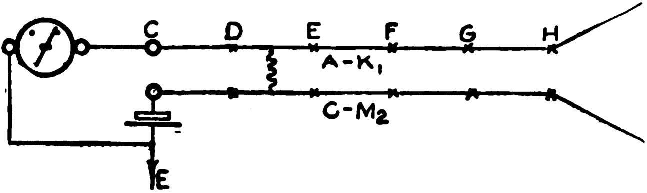


FIG. 471.—Localizing a contact.

INTERMITTENT FAULTS.

Faults of this class require the very greatest care in localization in order to avoid mis-tests. They are localized in precisely the same manner as the permanent faults already dealt with. If the fault is an intermittent earth the circuit is disconnected successively and it is ascertained by carefully watching for its re-appearance that it occurs when the wire is disconnected at one point and does not do so when the disconnection is one office nearer the testing station.

Where the wire cannot be given up for prolonged tests the locality may be ascertained by crossing successive lengths of the circuit with those of another circuit known to be in perfect condition.

For example, let A-F_3 (Fig. 468) be the faulty circuit and let A-F_2 (Fig. 469) be known to be in perfect condition. It is assumed that the fault does not very seriously affect the circuit and that the traffic is so heavy as to render it inconvenient to give up the circuit for testing purposes.

The following notes contain a summary of the operations involved :—

1. *B* is requested to cross A-F_2 and A-F_3 at —— (a time is given so that the message can easily be attended to at the time stated).

2. At the given time *B* makes the cross and *A* also crosses the two lines. If the fault re-appears on A-F_2 the fault is beyond *B*.

3. *C* is next told to cross the wires, and at the time given this cross is made and the wires put straight at *A*. If the fault now appears on A-F_2 it is evident that it is between *B* and *C*.

If the crosses are made rapidly and punctually, the circuits should not be interupted for more than one minute for each cross. Generally speaking, this method finds little favour, and it is only adopted when the faulty circuit cannot be spared and a wire cannot be given up to cross with it.

Underground wires are far less subject to faults than open lines, and when faults exist on lines partly open and partly underground it may generally be assumed that the fault is on the open sections, but when doubt exists a test is made to the pole test box at the end of the underground section.

COVERED WIRE FAULTS.

Earth faults upon covered wire circuits have certain well known and distinctive symptoms which differentiate them from faults upon aërial lines. A wire may be found to be below standard when tested in the morning, and with a small power, say 10 or even 20 cells, the circuit may appear to be almost perfect, although giving a better result with a positive than with a negative current. If the power is increased to 100 volts there is a marked difference in the insulation when tested with positive and negative currents respectively. With the former the wire appears fairly good, but almost to full earth with the latter. Immediately the negative current is applied the deflection gradually increases in value until a condition approaching full earth is observed. By reversing the battery the deflection just as gradually falls, indicating a greatly increased resistance.

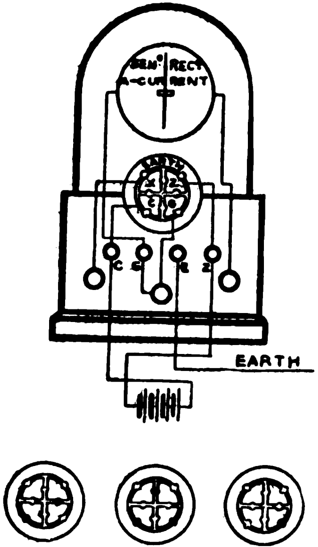
The explanation of the phenomenon is that a current flowing from the wire through the fault to earth forms an oxide of copper at the fault. This oxide, being an insulator, covers up and more or less perfectly insulates the fault. The reverse current, upon the other hand, reduces the oxide and keeps the wire clean, so decreasing the resistance of the fault.

The negative pole is joined to line on central battery circuits in preference to the positive in order to prevent electrolytic decomposition and disintegration of the conductor by the continuous formation of oxide at points of leakage.

Frequently a covered fault will wholly prevent the working of a long circuit, whilst it would have little or no effect upon the working of a very short or local circuit. In such cases a cross at the office and the end of the underground section will be highly beneficial, since the local office has only a very small power and also because the effect of a fault is felt far less. The effect of a fault of say 1000^{ω} resistance would be comparatively slight upon a local circuit with a line resistance of 50^{ω} or 100^{ω}, whilst its effect upon a circuit of 2000^{ω} resistance would be such as to produce a total stoppage.

Test Box Detectors

The various tests described are greatly facilitated by the use of the "Test Box Detector" (Fig. 472). The galvanometer is of the ordinary pattern, but a switch is added for the establishment of the various connections with the testing battery. This switch consists of four quadrants within a ring, and so arranged that any quadrant may be plugged to the ring or any quadrant may be connected to the quadrant horizontally or vertically opposite, but not diagonally. The four terminals marked *C*, *G*, *E*, and *Z* are joined up at the back of the instrument in the manner shown, whilst the three lower terminals are used for the various tests.



TO SEND A —CURRENT
TO TEST FOR CONTACT
TO RECEIVE A CURRENT

FIG. 472.—Test box detector.

The resistance of the Test Box Detector is 200ω and its figure of merit is 3·06 m.a., with which it should deflect to between 20° and 30°. With 20 Daniell cells a full deflection would result through about 2000ω.

The combinations which may be effected are as follows:—

1. To send a negative current, plug *C* and earth and *Z* and *G*. The wire is then connected to the right-hand terminal.
2. To send a positive current plug *Z* and earth and *C* and *G*.
3. To receive an earthed current plug *G* and *E* and connect the right-hand terminal to the wire upon which the current is to be received.
4. To observe a current upon a through wire the right and centre terminals are connected to the two sides of the circuit and all the plugs removed.
5. To test for contact plug *X* and *Z*, *C* and earth, and *G* and earth, the test being made by connecting the faulty wires to two outer terminals.

The arrangement which is used upon one-panel test boards of the switch spring pattern is shown in Fig. 473.

The galvanometer is of the test box pattern termed a "test box detector *C*," and the 7-test-hole tablet is mounted alongside. Each test hole is connected and lettered as indicated in the figure, and consideration will show that any of the combinations required may readily be obtained by the aid of the U-links.

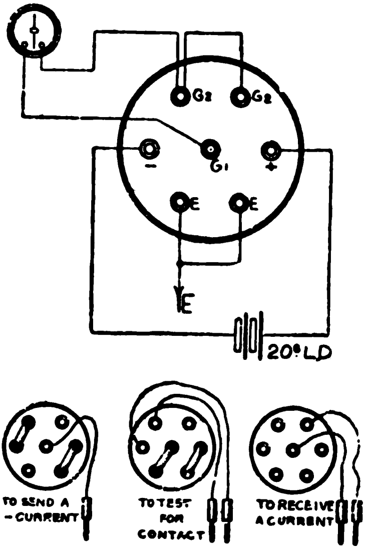


Fig. 473.—Test box detector "C" and 7-test-hole tablet.

Upon switch spring boards larger than the one-panel size a test tablet having 22 test holes is placed upon the rail between the panels. The upper portion, containing 8 test holes, is used for connecting the megger or other measuring apparatus to the lines for periodic and special tests. The lower set of 8 holes is connected to the test-box speaking sets and calls for no further comment. The central tablet provides precisely the same facilities as the 7-test-hole tablet just considered, and the method of making the various combinations should be quite apparent from Fig. 474. The galvanometer is of the ordinary differential pattern (see Fig. 132), and is mounted upon a turn-table bracket above the test-hole tablet.

In telephone trunk exchanges the 7-test-hole tablet allied with a differential galvanometer is frequently employed; the connections are, however, slightly different to those previously considered, but as they are indicated by the engraving, and since the arrangement has seldom, if ever, been used upon telegraph test boards, it will suffice to mention its existence.

CAUSES WHICH PRODUCE FAULTS.

As a conclusion to this section of the chapter it will be of interest briefly to consider the causes which produce faults upon the lines. The explanations will, however, assume some knowledge of the subsequent chapters, and this section may with advantage be re-read after construction has been considered. Faults upon aërial lines will be dealt with before, and separately from, underground faults.

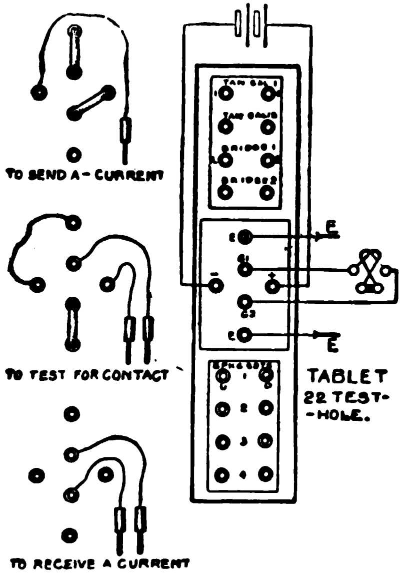


FIG. 474.—Test tablet (22-test-hole) used upon the larger switch spring test boards. Connections required for localisation testing are shown on the left. (The test holes marked Tan Gal. 1 and 2 are now used to connect up the Bridge Megger.)

With earth faults the degree is, of course, often dependent upon the climatic conditions, and a fault which in fine weather is slight may become full or total in wet weather. Moreover, the longer the circuit the greater is the deleterious effect of an earth fault of given resistance. Its effect also varies with its position, being most felt when in the centre and least when at the ends of the circuit.

A full earth may be produced by the line wire, released from the insulator, touching the earth wire upon the arm or by contact with any part of the metal upon an iron pole. The same effect results from the line wire coming into contact with anything which forms a good earth connection, such as a stay wire. With iron wire circuits the binding sometimes gives way, due to corrosion, and the effect of the wind releases the line wire. Again, the insulator may be broken by stone-throwing, a practice which cannot be entirely stamped out, notwithstanding the efforts of the police and the frequent prosecutions which result.

Much difficulty is caused by the proximity of trees, and in wet weather a very pronounced fault may be caused by the line wires becoming entangled with the branches. Along country roads it is most difficult to avoid the trees which overhang the footway, and occasionally some difficulty is experienced in enforcing permission to cut away the branches which jeopardize the satisfactory working of the circuits. Serious break-downs resulting in the total stoppage of a route are usually caused by trees being uprooted by a gale and blown over upon the line.

Earth faults of a slight character are often caused by broken or cracked insulators—usually the result of stone-throwing. When the line wire is released and rests upon a dry portion of the wooden arm, remote from the earth wire, the resultant fault is not of a very pronounced character. Similar remarks apply to contacts between the wires and the branches of a tree. In fine weather these defects are of a slight character, but during the prevalence of rain become much more pronounced.

Intermittent faults are produced by any of the causes mentioned, but the conditions are varied by the wind causing the wire to move. A wire may be blown into contact with a stay by each gust of wind, or conversely the stay may be brought into contact with the line by boys swinging upon the stay wire or by cattle rubbing against it. Again, the gusts of wind may blow the wires into contact with the branches of a tree, for it must be remembered that the wires may be swung outwards to a distance almost equal to the amount of their sag or dip.

Some of these intermittent faults result from the most extraordinary and unlooked for causes, but it would scarcely be profitable to give a long list of these happenings.

Contacts are produced by defective regulation of the wires or by a wire, released from its binding, making contact with one of the other lines. Also, contacts very frequently result from pieces of wire, chain, kite-strings, etc., being thrown over the wires. If a piece of wire or chain lies upon the roadway it is only a question of *how* long it will be before it is thrown on to the wires, and this is why telegraph foremen and linemen are so careful never to leave any odd piece of wire upon the road. In wet weather string and cotton produce a fairly effective contact.

The absence or defective condition of the earth wires upon a long line produces "weather contact" (*q.v.*), whilst a defective earth at a telegraph office results in an apparent contact between all the circuits. Slight contacts are usually produced by substances of low conductivity being thrown across the wires. In one case (in England) such a fault was found to be caused by the dead body of a snake!

Intermittent contacts usually result from the action of the wind, and the wires are blown together at each gust, or a chain or a piece of wire depending from one wire swings into contact with another. But little imagination is needed to indicate how many possible variations of these effects may produce faults.

A disconnection is caused by the breakage of the wire, which may be due to defective joints, defective regulation, natural decay of the wire produced by the action of the elements or by chemical fumes with which the air in the particular locality is laden. Again, the wires may be broken during blasting operations, near rifle ranges, or by trees, chimneys, or other objects falling upon the line. Defective joints are comparatively rare. When the renewal of the wire has been too long delayed breakages occur at the weakest positions, but it may be pointed out that, if the gauge of a wire is *uniformly* reduced by oxidation, the factor of safety remains unaltered, because the weight of the wire per unit length, and therefore the stress upon it are both correspondingly lessened. With copper wire erected in country districts oxidation is practically unknown, but in course of time (20 to 30 years) the wire becomes very brittle and breakages result. When the air is laden with fumes from chemical works the wire, of course, decays much more rapidly.

Yet another cause of trouble is the accumulations of snow and ice which adhere to the wires, thereby very greatly increasing the stress upon them. It is, however, only in acute cases that the wires are broken, but it is often necessary to cut and regulate them when the snow and ice have disappeared.

Kinks in the wire, due to careless handling in erection, and flaws or defects in manufacture may produce fractures, but these causes do not often operate owing to the efficiency with which the work is carried out and the care with which the various tests are made at the manufactory before the wire is accepted.

If the fallen wire rests upon dry ground the resulting earth may be slight, but, usually, the line is to almost full earth and frequently in falling it makes contact with other wires below it.

A slight fault, *i. e.* defective continuity, may be produced by an unsoldered, or badly-soldered, joint—the former often resulting from the omission to make good after a temporary repair.

In every case dealt with so far, attention has been directed to the line itself, but, in addition, there are the pole test boxes, dummy fuse poles, ordinary test boxes, lightning protectors and fuses *en route*. Total and partial disconnections may be caused by broken or loose connections at any of these points. Earths are frequently found in the protectors, especially after thunderstorms. Again, the leads may be defective, but the possible causes are so many, and the actual number of faults so small, that a catalogue of all the ills to which a line is subject is quite unnecessary.

As regards underground wires, the section dealing with these wires in Chapter XXIII needs but little addition.

The chief danger to air space cables is from moisture entering the cable due to defective plumber's joints or the sheathing being pierced by picks or wedges when taking up the footway. Faults are extremely rare, but when they do occur serious difficulties result, owing to the large number of wires concerned. Frequently, by careful observation of the special tests, defects may be traced and removed before they have affected the working of the circuits.

PART III.—CONDUCTOR RESISTANCE TESTS.

It has been remarked that slight earth currents are nearly always present upon telegraph lines, and when measuring the conductor resistance it is therefore necessary to take two measurements, one with each direction of current. The true resistance may then be assumed to be equal to the arithmetic mean (sum divided by 2) of the two tests. Where the earth current is such as to produce a considerable difference the geometric mean (square root of the product) should be taken, as this is a nearer approximation. For example, let the readings obtained be 1520^{ω} and 1430^{ω}, the actual resistance of the circuit is then $\dfrac{1520 + 1530}{2} = 1525^{\omega}$.

In this case the geometric mean, *i. e.* $\sqrt{1520 \times 1530}$, is practically the same. Had the two tests given 50^{ω} and 150^{ω} the results obtained would differ considerably, the arithmetic mean being 100^{ω} and the geometric mean ($\sqrt{50 \times 150}$) being $86{\cdot}6^{\omega}$, which is very approximately correct. To summarize, it may be said that where the two tests differ but little the arithmetic mean is sufficiently correct, whilst in cases of considerable percentage difference the results so obtained are too large and the geometric mean should be taken.

Another way of dealing with earth currents is to balance to a "false zero." The zero of the galvanometer is considered to be at the value of the deflection obtained when the galvanometer key only is down. It must, however, be remembered that every time an alteration is made in the resistance in the box this deflection is altered, and therefore the process is somewhat tedious. A balance is obtained when the deflection obtained by depressing both keys is equal to that produced by the galvanometer key alone. Yet another method consists in bringing the needle to zero by means of a magnet, but the same objection applies as to the previous method, viz. that every alteration in the resistance entails a readjustment of the magnet. It may, however, be added that the operation of taking the tests is scarcely as troublesome as would be expected. A third method (due to C. E. Hay) consists in placing an 8 m.f. condenser in series with the Paul galvanometer on a Wheatstone bridge and obtaining a balance in the ordinary way. Kicks take the place of permanent deflections during balancing operations.

INDIVIDUAL RESISTANCE OF A NUMBER OF CIRCUITS BETWEEN THE SAME TWO POINTS.

It is frequently required to measure accurately the resistance of several wires between two particular points. The use of an earth connection for this purpose is not entirely satisfactory, since slight earth currents are always present and the resistance of the earth connection itself is a somewhat uncertain quantity. Moreover, electric tramway systems have been rapidly developed, and the leakage currents vary in value from moment to moment, and thus render the taking of an accurate balance most difficult—if not actually impossible. In such cases, where three or more wires connect the two points in question, the individual resistances of the wires can readily be obtained. At the distant end the wires are all bunched together, and the resistances offered by various combinations are measured.

Let *A*, *B* and *C* (Fig. 475) represent three wires, the individual resistances of which are required. The following tests are made:—

1. The resistance of *A* and *B* is measured
2. „ „ *B* and *C* „
3. „ „ *A* and *C* „

The results of the first two tests added together give the resistance of *A*, the resistance of *C*, and twice the resistance of *B*. If the result of the third test (*A* and *C*) is now deducted the remainder is equal to twice the resistance of

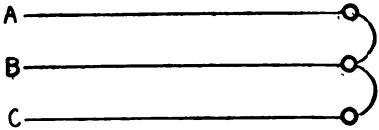


FIG. 475.—Wires looped for the individual conductor resistance tests.

B. Dividing this by 2 gives the resistance of *B* alone, whence the resistances of *A* and *C* are at once evident.

As an example let the results of the tests be as under:—

$$
\begin{array}{llll}
(1)\ 231^{\omega} & (2)\ 255^{\omega} & (3)\ 234^{\omega} & \\
A \text{ and } B & = & 231 & \\
B \text{ and } C & = & \underline{255} & \\
A \text{ and } C \text{ and twice } B & = & 486 & \\
A \text{ and } C & = & \underline{234} & \\
\text{Twice } B & = & 252^{\omega} & \\
B & = & 126^{\omega} &
\end{array}
$$

$$\therefore A = 231-126 = 105^{\omega}$$

$$\text{and } C = 234-105 = 129^{\omega}.$$

Had the number of wires been greater than three the same principle would be applied. Knowing *C* and measuring the value of *C* and *D* would determine *D*. Knowing *D* and measuring *D* and *E* would give *E*, and so on.

Formulæ after the fashion of that given below may be derived, but as the principle is so simple and obvious their utility is distinctly doubtful.

$$\text{Resistance of } B = \frac{\overset{(1)}{(A+B)}+\overset{(2)}{(B+C)}-\overset{(3)}{(A+C)}}{2}$$

PERIODICAL CONDUCTOR RESISTANCE TESTS.

The conductor resistance of every circuit is measured once a month by means of the Wheatstone Bridge, and upon this morning the ordinary insulation tests are omitted. The circuits are measured in pairs, and the same arrangements which are needed for the insulation readings serve for these tests. The results are valuable since, by comparing wires of the same gauge between the same points, any slight defect is apparent, whilst dry joints or loose connections are invariably advised, and dealt with in the same manner as other classes of fault. Pronounced defects of this character upon aërial lines invariably cause the needle of the Bridge galvanometer to oscillate from side to side.

The wires are where possible still tested as loops in order to reduce the number of separate tests required. Where this cannot be arranged, the circuit is tested to earth.

PART IV.—UNDERGROUND CABLE TESTS.

ELECTRIFICATION.

If an earthed battery and galvanometer are connected to a gutta-percha insulated wire disconnected at the further end (as shown in Fig. 476), it will be observed that the deflection produced continuously falls, thus indicating that the insulation steadily improves under the prolonged application of the battery. This phenomenon is usually, if not invariably, termed "electrification," but "absorption" or "dielectric polarization" would more accurately describe the effect. It is practically certain that the true insulation resistance does not improve and that the minute leakage current passing through the percha is constant. When the E.M.F. is first applied to the cable there is a heavy rush of current of short duration to charge it, and it seems probable that

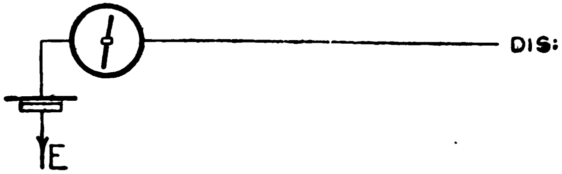


FIG. 476.—Connections for observation of electrification phenomenon.

there is some sort of yielding or soaking in of the charge and that this alone is responsible for the increase of the deflection above that due to the true leakage current through the dielectric. If the battery is removed and the earthed galvanometer connected to the cable a steadily diminishing current is observed, thus indicating the exudation of this extra charge. Another explanation lies in a possible polarization effect in the dielectric.

Precisely the same effect is observed with condensers, the phenomenon being more marked with those having paraffined paper, than with mica, insulation.

This effect is greater at low temperatures, but varies not only with the nature of the dielectric but with quality of material, being smaller in the best class of gutta-percha than in inferior grades. Kempe instances an experiment in which the insulation reading fell from 240 to 75 divisions in 90 minutes at 32° F., whilst at 75° F., with the same specimen, the deflection fell to but 173 in the same length of time. With india-rubber the deflection falls much more rapidly, but with a far smaller difference between the maximum and minimum readings. With paper cables the fall is still less.

In all measurements of the insulation resistance of covered wires the reading is taken after a prescribed number of "minutes' electrification," or in other words after the testing battery has been applied for that length of time. The phenomenon is quite independent of the value of the E.M.F. and of the direction of the current, but in repeating a set of measurements care must be taken that the whole of the electricity absorbed is discharged before attempting to do so. With long lengths of cable a considerable time must be allowed, the cable meanwhile being put to earth.

One other point which should be remarked is that with a perfect core the deflection falls in a regular and steady manner, and that any irregularity is presumptive evidence of a defect in the insulation. In addition to the readings, it should always be noted whether the electrification is steady or irregular.

With comparatively short lengths of air-space cable the phenomenon is very small, and the reading taken after one minute's electrification represents very approximately the true insulation.

THE GROUPING OF THE WIRES IN AN AIR-SPACE CABLE FOR INSULATION TESTS.

The insulation of an air-space cable is of the order of from 5000 to 50,000 meghoms per mile. In order to obtain readable deflections upon lengths of from 100 to 400 yards with ordinary measuring instruments, and also to reduce the number of tests to be made, the various conductors are grouped. It is essential that the insulation between every wire and every other wire of the cable with which it is physically possible for it to be in contact shall be proved. Therefore, no wire may be tested in the same group as its companion wire if a twin (or wires if a quadruple twin) cable, either wires of the pair on either side of it in the same layer, or any wire in either the layer directly above or below it.

Taking the case of the 74-wire cable illustrated in Fig. 477, the following groups may be formed :—

A — 39, 43, 47, 51, 55, 59, 63, 67, 71, 3, 7, 11.
B — 40, 44, 48, 52, 56, 60, 64, 68, 72, 4, 8, 12.
C — 41, 45, 49, 53, 57, 61, 65, 69, 73, 5, 9, 13.
D — 42, 46, 50, 54, 58, 62, 66, 70, 74, 6, 10, 14.
E — 15, 19, 23, 27, 31, 35, 1.
F — 16, 20, 24, 28, 32, 36, 2.
G — 17, 21, 25, 29, 33, 37.
H — 18, 22, 26, 30, 34, 38.

Each group may be tested provided all the other groups are, during the test, put to earth, and therefore, instead of 74 tests, but eight are needed. With a larger cable containing, say, 600 wires, the reduction in the number of tests is still more remarkable. It will be seen that the principle consists in grouping together only those wires between which it is physically impossible for a contact to occur. If group A gave an insulation resistance of 800 meghoms in a length of 220 yards, the per mileage insulation resistance of the whole group would be 100 meghoms, and the average insulation of each wire 1200 meghoms per mile.

From the example which has been given, and the statement of the underlying principle, it should be possible for the reader to work out the arrangement for any other type

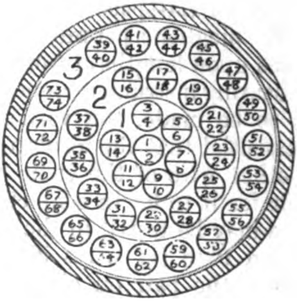


Fig. 477.—Arrangement of a 37-pair dry core cable.

of cable. For instance, a screened conductor cable could be tested in a single operation, since each wire is surrounded by a copper tape. The tests may most conveniently be made with a high range megger (*vide* page 163); the method of carrying out tests during the jointing of successive lengths of cable is reverted to in Chapter XXIII.

PART V.—TESTS FOR THE POSITION OF A FAULT AND RESISTANCE OF EARTH CONNECTION.

Varley Loop Test.

The exact position of an earth fault may be found by means of the Varley loop test when a perfect wire is available for the test. The resistance of the looped wires is measured in the ordinary way, and the connections are then altered to those shown in Figs. 478 and 479. In the former figure the principle of the test is indicated. It consists in throwing the rheostat arm into the circuit and, by earthing the battery, connecting it to the point at which the fault exists. When a balance is obtained the product of $C\ A$ and $(B\ D + O\ F)$ is equal to the product of $C\ B$ and $M\ N\ P\ F$. Assuming that $C\ A = C\ B$, then the resistance (x) of $O\ F$ is obtained

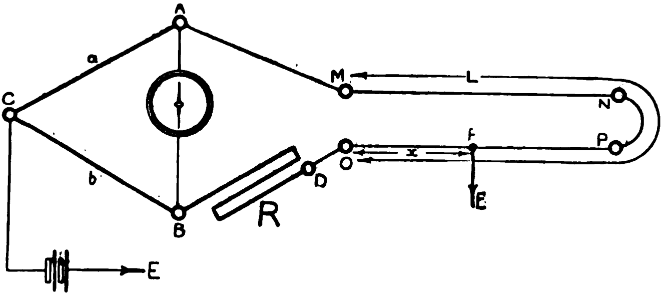


Fig. 478.—Principle of the Varley loop test for the position of an earth fault.

$$x = \frac{L - R}{2}$$

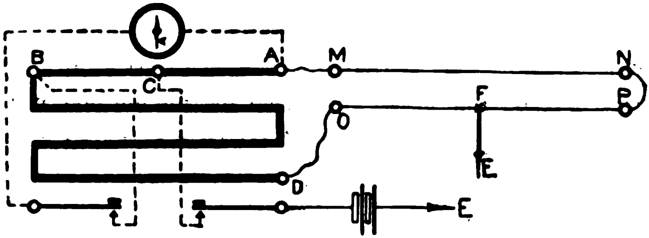


Fig. 479.—Connections of bridge for the Varley test.

where L is the resistance of the loop obtained by the first test and R is the resistance unplugged in $B\ D$ to obtain a balance.

For example, let $L = 800$ and $R = 400$, then $x = \frac{800 - 400}{2} = 200^{\omega}$, which is the resistance of the line up to the point at which the fault exists.

Where a and b are unequal $a(R + x) = b(L - x)$

whence $$x = \frac{bL - aR}{a + b}$$

It will be observed that the resistance of the fault does not enter into the calculation at all, its only effect being to reduce the difference of potential applied between C and F.

The result of the test gives the resistance of the faulty wire between the testing office and the point at which the fault occurs, and, with the aid of the records of conductor resistance tests, the distance of the fault in miles from the testing office may readily be obtained. In the case of underground circuits the position may be obtained with very considerable accuracy since, owing to the constancy of the temperatures, the resistances of the wires do not vary. Consideration will show that this test as well as the contact test may be carried out with a Bridge Megger.

The test is a very accurate one when the resistance of the fault is low and the insulation is high. If the fault is a slight one and approximates to the insulation of the rest of the circuit the results obtained are valueless. The whole principle lies in the assumption that there is one definite fault upon an otherwise perfectly insulated pair of wires.

The position of an earth fault upon one of the wires in a lead-covered cable may be localized by this method, but as the resistances of the sections tested are usually low the ratio arms are made unequal, and care is taken to observe the resistance of the leads employed.

MURRAY LOOP TEST.

The Murray loop test may be used in precisely the same circumstances and, under some conditions, is to be preferred. The arrangement is illustrated in Figs. 480 and 481, from which it will be seen that the four arms of the bridge are formed by BC, BD, MF, and $FNPO$. When a balance is obtained $BC \times OPNF = BD \times MF$, *i. e.*

$$b(L - x) = Rx$$

whence $$x = \frac{bL}{R + b}.$$

where $x =$ resistance of $M F$
$b = B C$
$R = B D$
$L =$ resistance of the loop $M N P O$ obtained as in the Varley test.

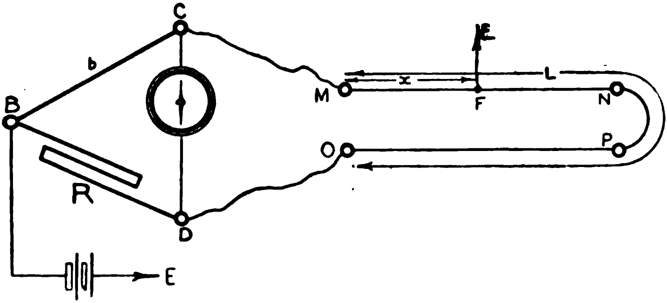


Fig. 480.—Principle of the Murray loop test for the position of an earth fault.

As an example, let the resistance of the loop $= 100^{\omega}$ $b = 100^{\omega}$, and $R = 536^{\omega}$; then $x = \dfrac{100 \times 100}{536 + 100} = 15{\cdot}7^{\omega}$ approx.

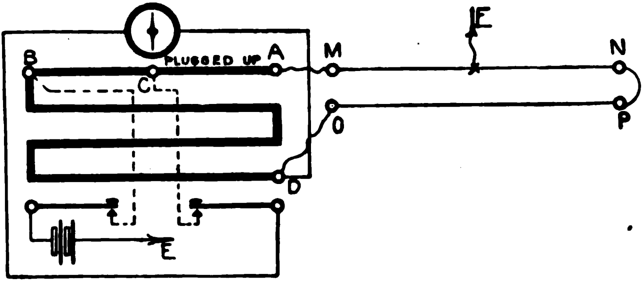


Fig. 481.—Connections of the bridge for the Murray test.

Similar remarks as regards high resistance faults upon circuits having a low insulation resistance apply to this as to the Varley test.

TESTS FOR THE POSITION OF A CONTACT.

The position of a contact may be obtained as indicated in Fig. 482 (compare with Fig. 478), but where possible it is preferable to avoid the use of earth by employing a third wire. The Murray test may be applied to this case quite readily, but it is believed that the principle is now sufficiently apparent.

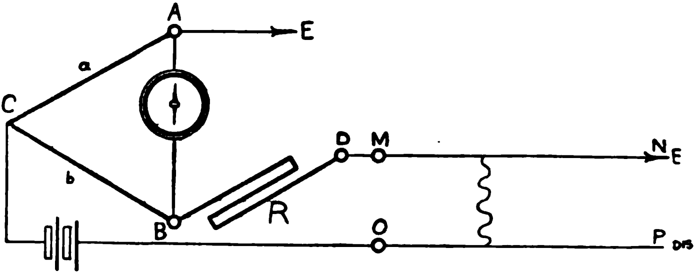


FIG. 482.—Varley test for the position of a contact fault.

POMEROY'S METHOD OF TESTING EARTHS.

It is frequently necessary to obtain the resistance of an earth connection, and, by making the two tests shown in Figs. 483 and 484, this may be accomplished with a fair amount of accuracy. Two lines connected to two independent earths are required for the tests and are joined up as shown. It is necessary that the value of the current

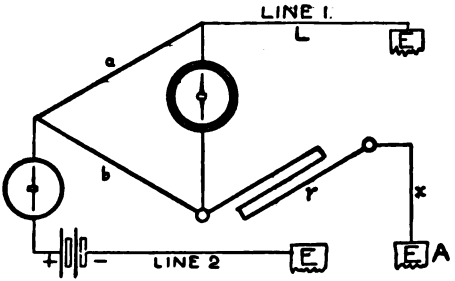


FIG. 483.—Pomeroy's test for the resistance of an earth; first reading.

passing at the earth plate should be approximately equal in both cases, and the battery power required for the second test should therefore be increased accordingly. This may best be judged by inserting a detector in series

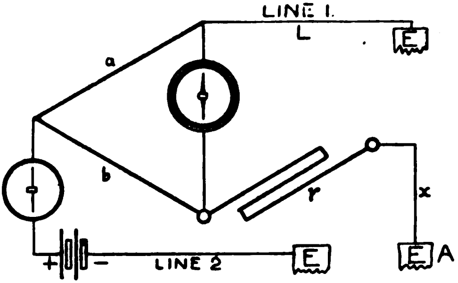


FIG. 484.—Pomeroy's earth test; second reading.

with the battery as indicated. The battery connections are reversed in the second test, so that the direction of the current from the plate at *A* may be the same in both tests (*L* includes the resistance of the earth upon Line 1).

1st test. $a(r + x) = bL$
2nd test. $aR = b(L + x)$

whence
$$x = \frac{a(R - r)}{a + b}$$

or when the proportionals *a* and *b* are equal:—

$$x = \frac{R - r}{2}$$

that is half the difference between the two resistances required to produce a balance.

PART VI.—TRACING INSTRUMENT FAULTS.

The commonest fault which occurs on apparatus is a disconnection produced by terminals not being tightly screwed up, by dirty or other defective contacts or broken wires. Earth faults are not so frequent nor are contacts, but it is a cardinal principle that the apparatus should always be tested before proceeding to make tests of the line. This is easily accomplished from the instrument side from the test-box.

The effect of an earth fault on a line is to increase the current sent out and diminish the current received. A contact causes the signals sent on one circuit to be received on the circuit with which it is in contact.

In tracing instrument faults much time is saved by obtaining as many facts as possible as to the conditions of working in which the defect operates or does not operate and thus to reduce the area of the examination. For example, the single current sounder set (Fig. 119) may be divided into main, sending, receiving, and local circuits. The main circuit is that common to both sending and receiving, viz. from the centre of the key through the galvanometer to line or earth, as the case may be, and also *U*-circle of the relay to line or earth. The sending circuit is from *U*-circle, through the battery and front contact point. The receiving circuit is through the back stop and relay to *U*-circle. The local circuit comprises the sounder, local battery and *T M* contacts.

As an example of the deduction of the position of a fault, let the symptoms be that the call cannot be stopped. The reception of signals proves the main circuit at both ends, the receiving circuit at the receiving end, and the sending circuit at the sending end. This leaves the sending circuit and distant receiving circuit. If depression of the key cuts the circuit the fault is in the sending circuit. If not, the fault is in the distant receiving circuit, *i. e.* in the circuit through the back stop of the key and the relay. If it is noticed that, upon holding down the key, a current is sent out when the distant station obviously has his key at rest, the fault is either short-circuit of the relay or possibly the local battery circuit is defective, and the movement of the galvanometer needle has not been noticed.

Key faults in the double current set shown in Fig. 128 are comparatively rare since all the permanent connections are made by means of brass straps beneath the base. One of the contacts between the divided lever and the springs occasionally becomes dirty or bent or, in the adjustable contact type, one of the screws may need adjustment, with the result that the key sends out only one current. Faults in the switch are comparatively rare.

If, after having called for some time, it is noticed (from the galvanometer) that the distant station is endeavouring to stop the call, the fault will lie in the caller's receiving circuit. If upon the proving test explained on page 247 it is found that the relay is unaffected by the caller's key, the fault is in the key switch. Occasionally the connecting wires break inside their covering and thus cause intermittent faults.

Two defects of apparently opposite character may be produced by defective regulation. Sticky dashes and missed dots may be caused by insufficient bias upon the relay and too much tension upon the spring of the sounder. It may also be caused by the armature of the sounder being allowed to approach the cores too closely, with the result that the marks stick. Instead of this being put right the spacing bias is increased and sticky dashes still occur whilst the dots are missed.

Here it may be pointed out that the disconnection of one coil of a differentially wound instrument may enable it to work when its coils are in parallel.

In duplex sets a further division of the circuits may be made to include those parts used only in duplex working and those common to both duplex and simplex. In the single current duplex (Fig. 138) it should be remembered that the battery resistance coil r shunts the $U\ D$ coil of the relay at simplex, and that inability to work duplex whilst simplex working is possible could be produced by the disconnection of the $U\ D$ coil.

In the case of the double current duplex shown in Fig. 148, consideration will show that a disconnected line causes the sender's marks to be received reversed upon the home apparatus, and this still happens when the rheostat resistance is increased.

An earth upon the line reduces the normal deflection upon the home galvanometer, and when the switches at both ends are turned to simplex, the deflection when sending greatly exceeds that when receiving. The resistance in the rheostat required to balance is also greatly reduced.

Disconnection of the condenser is revealed by split marks, and the fact that alteration of the plugs produces no effect. A short circuit in the condenser renders the rheostat inoperative, and the sender's marks are received reversed.

A rather puzzling fault which occasionally occurs is due to one of the shunts across the galvanometer coils becoming disconnected. The result is that when a balance has been obtained by the galvanometer the working signals are split up when both stations are simultaneously working. This is immediately detected if the signals are rectified by altering the resistance in the rheostat. The signals are then correctly received, but the home key causes the galvanometer to deflect.

A similar fault is occasionally produced by the insulation of the galvanometer or the relay coils giving way, and so short-circuiting a number of turns of wire.

A heavy loss upon a circuit frequently precludes duplex but not simplex working. When a wire is earthy, its resistance, and consequently the resistance required in the rheostat to balance it, is greatly decreased. The strength of the current in both line and compensation coils is therefore correspondingly increased, but these two effects balance. If, now, three-fourths of the current from the distant station flows to earth one-fourth only will be available at the distant end. This fraction of the current acts solely upon one coil of the relay, whereas in simplex working the current would pass through both coils of the relay in series. The pull upon the tongue of the relay would be quite twice as strong in the latter as in the former case.

Let the set shown in Fig. 398 work duplex satisfactorily, but when turned to simplex working is stopped. The fact that duplex working is possible proves that the battery, galvanometer, relay, and rheostat are perfect, and that the connections to line and earth are in order. If the stoppage is inability to send or receive, connection is not made between the bottom and right-hand terminal through the strap to the upper terminal of the duplex switch when turned to simplex. If, however, currents are sent out but not received, the fault lies in the circuit from the lower right-hand terminal of the key, through the key and duplex switch connections to the top terminal.

Consider now the case in which simplex, but not duplex, working is satisfactory. The fault, excluding lack of differentiality in the galvanometer or relay, can only be in the connection made by the upper half of the duplex switch or in that made by the lower half and thence to the split of the relay. In the latter case, the key has no effect on the galvanometer when the rheostat resistance is varied.

The cases discussed have for their object the demonstration of the principle by which the defective portion of the apparatus may be located by the symptoms of the fault, and the reader is advised to sketch the full connections of various sets of apparatus and then to consider the various effects which will be produced by faults in various positions. For example, it will be observed that since the current sent out by a single needle commutator passes through the back stop of the key which is at rest a disconnection in the receiving circuit cannot exist at these points if both keys send out current.

In the case of quadruplex working it is necessary to have a ratio of one to three between the *A* and *B* currents and equal powers should be used at the two ends.

If the *B* key has no effect upon the strength of the current received at the distant end it is obvious that the *B* battery is short-circuited. If disconnected the *A* marks received at the distant end would be destroyed and the balance upset whenever the *B* key was in the faulty position.

A fault in the *A* key causing it to send out only one current would break up the distant *B* marks, but would not affect anything else, as it is quite possible that the distant *A* side would be re-regulated to work with but one current without the cause for the alteration being discovered. At the office where the defect exists the signals would be received perfectly upon both the *A* and *B* sides. Such faults should, however, be discovered when observing the ratios of the received currents upon the differential galvanometer.

A disconnection in the line or compensation coils of the relays or galvanometer should readily be located as in duplex working.

A contact between the two coils of the relays or galvanometer is evidenced by impossibility of balancing. If in the *B* relay, it will be possible to balance in the ordinary way, but the *B* relay will not then be differential. If the contact is near the *D* and *U*-circle ends of the relay it will be equivalent to cutting it out altogether. A contact at any other point will have similar results, viz. that when the circuit is balanced by the galvanometer the keys still affect the apparatus.

A short-circuit in the coils of any of the relays or galvanometer produces a like result, but here it is possible to clear the marks on both *A* and *B* relays by disregarding the galvanometer and balancing by observing the effect upon the working signals. If either relay has a short circuit then the faulty relay is affected by the keys when both the galvanometer and the perfect relay are balanced.

Faults in the local circuits are self-evident, and the adjustments have already been dealt with.

In observing the received currents both the distant keys should be proved in each position and the distant station should similarly observe the home apparatus. In the majority of cases the trouble lies in the adjustment of the *B* side, and faults such as those described are comparatively rare.

Wheatstone circuits have their special faults, of which defective regulation of the transmitter is probably the most frequent; but the principles given in this chapter may be applied to locate defects, and the apparatus special to automatic working with its connections should form a further division in splitting up the circuit into its component parts.

Repeater faults are dealt with specially in Chapter XIX.

Faults in the sending circuit are easy to locate, the most frequent causes being broken wires, terminals not screwed up tightly, dirty key contacts or blown fuses. In secondary cell-worked offices a portable voltmeter is used for testing the power, and with its aid a few moments only need be occupied in tracing faults due to the power supply.

PART VII.—THE MAKING GOOD OF FAULTY CIRCUITS, SPECIAL ARRANGEMENTS, AND EARTH CURRENTS.

SYMBOLS USED FOR LINES AND APPARATUS UPON PLANS.*

In order to represent the various classes of apparatus in use upon the circuits, the symbols shown at the base of Fig. 485 are employed on circuit plans to denote Post Office apparatus; rented apparatus is shown in outline symbols, and in the case of apparatus not owned by the Post Office the symbols are of dotted outline. The lines themselves are indicated by coloured lines as under:—

UPON MAPS.

Open lines on roads and canals . . .	Green.
„ „ „ railways	Red.
Covered „ „ roads, canals, and railways, in pipes.	Blue.
„ „ „ „ „ „ „ in boxing.	Brown.

THE "MAKING GOOD" OF FAULTY CIRCUITS.

As previously stated, it is frequently possible to "make good" a defective long circuit, by crossing the faulty section with that of a shorter circuit without seriously affecting the working of the latter. Such a case is illustrated in Fig. 485, where the lines between *B* and *C* have been crossed so as to make A-Q_1 good by throwing the fault on to the short A-D_2 circuit. Crosses are made at the test boxes at *B* and *C* (see Fig. 435).

One good circuit may frequently be formed from two defective ones by the insertion of suitable crosses. Such a case is shown in Fig. 486, where No. 1 wire has been made

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* "Circuit Plans," by T. Howlett. *P. O. Electrical Engineer's Journal*, Vol. VI, p. 61.

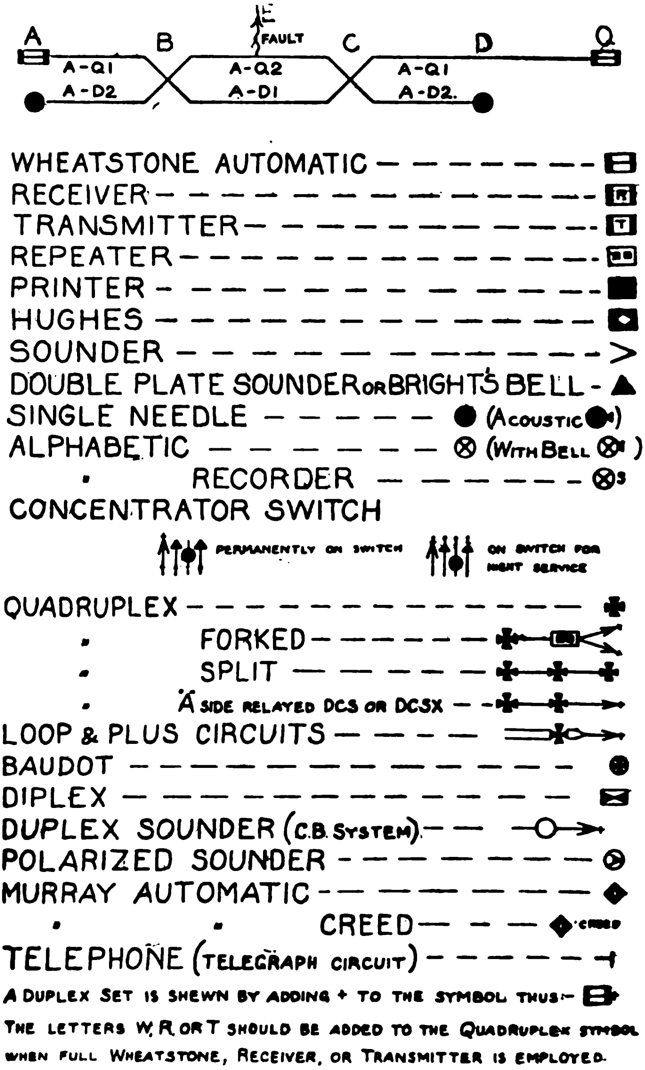
A
B
E
FAULT
C
D
Q
A-Q1
A-D2
A-Q2
A-D1
A-Q1
A-D2.
WHEATSTONE AUTOMATIC
RECEIVER
R
TRANSMITTER
T
REPEATER
PRINTER
HUGHES
SOUNDER
DOUBLE PLATE SOUNDER OR BRIGHT'S BELL
SINGLE NEEDLE
(ACOUSTIC)
ALPHABETIC
(WITH BELL)
RECORDER
S
CONCENTRATOR SWITCH
PERMANENTLY ON SWITCH
ON SWITCH FOR NIGHT SERVICE
QUADRUPLEX
FORKED
SPLIT
A SIDE RELAYED DCS OR DCSX
LOOP & PLUS CIRCUITS
BAUDOT
DIPLEX
DUPLEX SOUNDER (C.B. SYSTEM)
POLARIZED SOUNDER
MURRAY AUTOMATIC
CREED
CREED
TELEPHONE (TELEGRAPH CIRCUIT)
A DUPLEX SET IS SHEWN BY ADDING + TO THE SYMBOL THUS:-
THE LETTERS W, R, OR T SHOULD BE ADDED TO THE QUADRUPLEX SYMBOL WHEN FULL WHEATSTONE, RECEIVER, OR TRANSMITTER IS EMPLOYED.

Fig. 485.—Making good a faulty circuit, also symbols used to represent various forms of apparatus.

good with the *B-C* length of No. 2. There is some advantage in throwing both faults on to No. 2, and putting the wire through, since in this way the faults may be kept under observation.

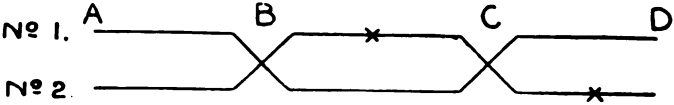

FIG. 486.—Making one good circuit from two faulty ends.

As an example of a case which may arise in practice, suppose that a London-Belfast wire, relayed at Preston and passing through Carlisle, is faulty between Stafford and Preston, whilst a London-Glasgow wire (going via Leeds) is faulty between Carlisle and Glasgow. The Belfast circuit would be made good by a cross at Carlisle, and Leeds would be asked to introduce a repeater. Both faulty sections would thus be thrown on to the Glasgow wire, which would be kept under observation.

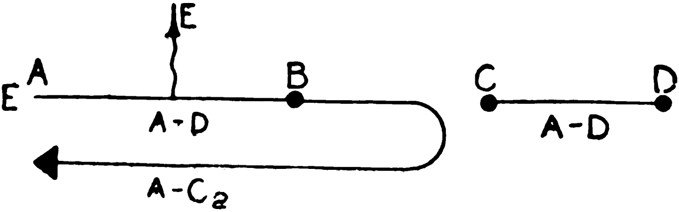

FIG. 487.—Making good a faulty circuit.

In Fig. 487 an example is given of a case in which the circuit serving *A*, *B*, *C* and *D* is faulty between *A* and *B*. It is assumed that *C* is an office where testing facilities are provided, and that a wire A-C_2 is available for crossing purposes. By terminating the *C D* section at *C* and forming an *A-B* circuit as indicated all the offices are provided for, but re-transmission at *C* is rendered necessary.

The A-D_3 news wire serving *B*, *C* and *D* is shown faulty between *B* and *C* (Fig. 488), but has been made good with A-D_2, which, however, does not pass through *B* and *C*.

The only change that requires comment is that the apparatus at *A* requires to be made intermediate, the *U* and *D* terminals being joined to *A*-D_2 and *A*-D_3 respectively. If secondary cell working is in vogue at *A* a special set would

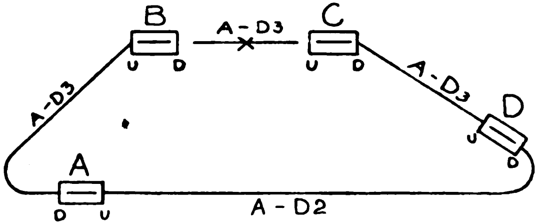

Fig. 488.—Making good a faulty circuit.

be used, and the short line joined to *A*-D_3, the set being reversed with the peg-switch.

The same result could be obtained by forking the circuits at *A*, but the method indicated is to be preferred when an intermediate or special set is available.

THE FORMATION OF SPECIAL CIRCUITS.

It is, of course, quite impracticable to provide each office with sufficient circuits to deal with every emergency which may arise. There is, however, a number of reserve wires which may be used for special purposes, such as race meetings, speeches, cricket and football matches, etc., and, by suitably manipulating the various circuits, almost any emergency may be provided for. In forming these circuits the guiding principles are to produce the minimum amount of disturbance to the ordinary traffic arrangements, and to use open wires upon all long circuits. The work demands a knowledge of the routes of the various wires, but this is a part of the education of every testing officer. If the record of the testing sections of each wire (see page 727) is consulted, even this knowledge is scarcely essential.

It frequently happens that only one wire passes through an office where special work is to be dealt with, and that this particular wire cannot possibly be given up. In such a case a wire can usually be found to make good the circuit required. For instance, A-Q_1 passing through B, C, and D can be made available by crossing it with A-D_1 at A and D. The number of wires may be doubled by terminating both sides of a through wire and doubling it back at the nearest testing point where a wire is available for the purpose. The guiding principles having been stated, local illustrations may readily be supplied by the reader.

It is often necessary to fork circuits so that items may be signalled to two or more offices, and in case the circuits forked are of unequal resistance, resistance may be added at the test box as shown in Fig. 435. On switch spring test boards the necessary connections are made with the aid of the grouping springs. The two forked offices are reversed to each other, and where this is of consequence a forked repeater must be introduced at the forking office.

The battery power requisite to work the circuits is found as described in Chapter II, but it may be convenient to summarize a few useful points.

I. The per mileage resistance of an iron wire $= \frac{5328}{\text{weight per mile}}$ ohms.

II. The per mileage resistance of a copper wire $= \frac{878{\cdot}73}{\text{weight per mile}}$ ohms.

III. (*a*) Where secondary coils are used, the E.M.F. required is the nearest value in excess of that obtained by multiplying the required current in amperes by the *total* resistance of the circuit (the resistance of one lamp resistance or metal-cased resistance coil, as the case may be, must be added).

(*b*) Where Leclanché batteries are used the number of cells required may be found by dividing the resistance of the circuit by 71 if 14 m.a. and by 48 if 20 m.a. required.

The term "resistance of the circuit" in III. (*a*) and (*b*) includes the resistances of the line and apparatus, but not the internal resistance of the battery, which is taken account of in the rules given.

IV. Covered wire should be avoided upon all long circuits owing to the reduced speed of working which it entails. With submarine cable circuits the repeater should be placed as near to the cable as possible (see page 634).

The only point which remains for comment is that occasionally an emergency arises and sufficient battery power is not available at a small office for working over a long specially formed circuit. This case may usually be met by interpolating a repeater at the nearest large office.

Central battery working should be adopted where possible (*vide* page 531).

EARTH CURRENTS.

Two similar metallic plates immersed in two different electrolytes, separated by a porous partition, will form a voltaic couple, and therefore generate a current. There is no doubt that a slight current is produced by the two earth plates at the ends of a telegraph circuit, but this effect is of so minute a character that its effect upon the circuit may be ignored. There are also stray currents which are produced by leakage from the uninsulated return conductor (the bonded rails) of electric tramway systems. Since the difference of potential between any two points upon the system is limited to 7 volts under the Board of Trade regulations, but little trouble is experienced on this account. There are cases, however, in which local circuits having the same general direction as the tramway have been seriously affected. One remedy is to increase the resistance of the circuit by inserting a resistance coil and correspondingly to augment the battery power. As the current due to a given difference of potential is inversely proportional to the resistance, it will be obvious that the disturbing current may be reduced to negligible dimensions. It may be added that the leakage current varies from time to time, and that therefore an opposing battery cannot be inserted in the line so as to balance it.

It is found that different parts of the earth are frequently at different potentials, and that consequently "earth currents," as they are termed, flow over the circuits between the various points. In the case of very long submarine cables these currents are of sufficient magnitude to make direct working quite impracticable. For this, and other important reasons, condensers are inserted at either end of the circuit, thus preventing the passage of a steady current through the cable. Long land lines and short submarine cables are normally unaffected by earth currents and provision against them is unnecessary.

The precise cause of earth currents has yet to be discovered.* There is, however, no doubt that they are always in evidence during periods of "magnetic" storm, *i. e.* during periods in which the declination, horizontal force and vertical force show considerable and irregular variations. When the aurora, observed chiefly in the Arctic regions, is of a rapidly-varying character magnetic storms and earth currents are invariably observed. The association of sun-spots with periods of magnetic storm has been suggested, but evidence shows that several specially large sun-spots have been unaccompanied by magnetic storms. Again, there is no evidence of any connection with earthquakes or other internal troubles of the earth itself.

As none of the theories which have been given altogether fit the observed phenomena the true cause is, at present, quite an open question.

Generally speaking, lines running N.E. and S.W. are most frequently affected, whilst those running N.W. and S.E. are seldom disturbed. A very severe magnetic storm occurred on November 1, 1903, and it was accompanied by unusually large earth currents. In England, the circuits were affected from 7.0 a.m. to 8.0 p.m., and for some hours the service was completely disorganized. Earth currents up to 60 m.a. were observed, whilst the direction and value varied from time to time. A similar state of affairs occurred in France, and Paris was unable to communicate with the greater number of French towns, and was also cut off from communication with America, Spain, Portugal, Italy, Algeria, Tunis, and many other places. Communication was re-established on the French lines at 4.40 p.m., but was interrupted at about 5.30 for a short time. Working on the London-Paris telegraph cable was also disorganized, but the Post Office submarine cable to Germany was less affected, although there was considerable trouble on the land lines serving it. From New York it was reported that a bright aurora was visible on the date in question—as was also the case in some parts of these islands—and that earth current disturbances were felt in all directions, in some instances causing a total cessation of telegraph business. According to one New York correspondent a voltage of 675 was observed.

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* See *Electrician*, November 6, 1903, p. 95, "The Magnetic Storm." The present account is taken very largely from this article.

The long submarine cables were less affected than the land lines, and those upon which condensers and siphon-recorders are employed were hardly disturbed at all. Where Morse working was used, very considerable difficulty was occasioned.

The remedies against earth currents consist in the use of a metallic circuit, or in the interpolation of condensers. The former remedy is, of course, a complete one so far as the disturbances are concerned, but it reduces the number of circuits by half.

Metallic circuit working can be arranged between two offices worked with individual batteries by removing the earth connections at each end and substituting the line to be used as return. This doubles the resistance of the line and increased battery power may be necessary. Where secondary cell working is employed the return line is connected to the relay at each end of a double current simplex circuit and a switch interpolated in the connection between each relay and earth. The switch is turned to the earth side when sending, and thus the earthed battery sends out a current along the line through the distant apparatus and back along the return line to the earth connection formed by the switch to the earth of the sending battery. In the case of duplex or quadruplex circuits the rheostats are joined to the return wire and switches provided to earth the return wire at the sending end when signalling. On repeaters a relaying sounder may be placed in series with each automatic switch so that the earth connection required when sending may be made automatically.*

The second remedy (the insertion of a condenser in the line) is illustrated in Fig. 489. Both galvanometers, the relay at the sending end and the key at the receiving end, have been omitted in order to simplify the diagram. The relay must be set neutral, since a momentary current flows only when the position of the key is changed. As, however, the condenser prevents the passage of a continuous current no effect is produced either by a steady or by a slowly varying earth current.

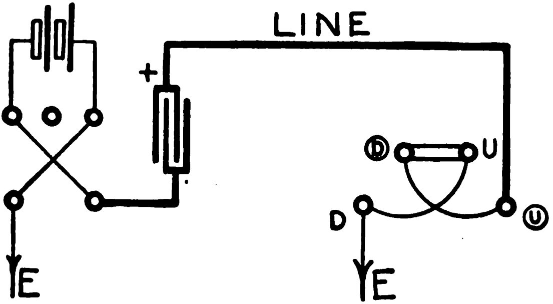

FIG. 489.—Working through a condenser so as to eliminate earth currents.

For many years it has been common practice to insert condensers in the lines at relay stations during the prevalence of earth currents, and no difficulty is ordinarily experienced. In slight cases it is frequently only necessary to raise the resistance in the rheostat of the shunted condenser upon Wheatstone circuits. It may perhaps be noted that a bridge duplex circuit would be less affected than a differentially worked one, on account of the relatively high resistance and smaller portion of the received current which flows through the relay.

On simplex double current sounder circuits a condenser of about 10 m.f. is inserted in the receiving circuit between the relay and the key. On secondary cell worked duplex and on all quadruplex circuits provided with condensers the switches are turned to simplex, the rheostat disconnected and the full capacity of the condenser inserted, but on individual battery worked duplexes the switch must be turned to duplex in order to bring in the condenser. Wheatstone simplex circuits are worked by disconnecting the reading condenser rheostat.

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* Vide *Connections of Telegraphic Apparatus and Circuits, G.P.O.* plate 25A.

CHAPTER XXII

THE CONSTRUCTION OF AERIAL LINES.

INTRODUCTORY.

TELEGRAPH lines may be divided into two great classes, aerial or overground and underground lines. Open work is preferable to underground on account of its greater cheapness, accessibility, and superior electrical properties. The capacity of an underground wire is far in excess of that of an open line, and consequently the working speed of the former is considerably less than that of the latter in the case of long circuits.

Aërial lines are erected upon poles on public roads, private property, railways, and canals. If a free choice can be made, the public road possesses by far the greatest advantages. The line is always readily accessible, and there is little chance of costly removals and diversions having to be made. Where the plant is placed upon private property the owner's consent must be obtained, and, if this is not hedged with impossible conditions, there is still the fact that it is within his power at any time to demand the removal of the fixtures by giving the stipulated notice. The result may be a diversion of the most costly character, or the difficulty may be met quite readily and cheaply, but the fact remains that every fixture upon private property is subject to the personal will or caprice of the property owner. Therefore every attempt is made to secure a route upon public roads before private wayleaves are considered.

Upon canals a wayleave payment has to be made, but the risk of compulsory removal is comparatively remote.

The railways, upon the other hand, have the disadvantage that the maintenance of the wires is usually in the hands of the company's staff, so introducing a dual control. It is certainly preferable that the lines and apparatus should all be under the control of one administration. Apart from this, the railways are well adapted for the erection of telegraph lines, since the banks of the railway provide such effective staying facilities. The poles may be quite short, since there are no buildings to cross; removals cannot occur as the result of external building operations, nor do the lines suffer from the proximity of growing trees. The lines are also more sheltered and less liable to damage by stone-throwing. The use of the train for inspecting lines probably leads to that duty being less efficiently performed than in the case of a road-line along which there is no means of travelling at so rapid a pace.

In large cities it is impracticable to place poles along the busiest streets, and either overhouse or underground construction is adopted. By the former term is denoted all cases in which the wires are carried upon standards erected upon the roofs or upon brackets fixed on the chimney stacks or corners of the various buildings *en route*. When there are from one to four wires the use of brackets is often economical, but when the number of wires necessitates the use of standards difficulties often arise owing to access to the roof being required when running additional wires, to remove faults, carry out repairs or renewals, and for inspectional purposes. Moreover, the average roof is not constructed with a view to the erection of a standard upon it, and invariably all damage to the roof is ascribed to the presence of the standard and access to it by workmen. This frequently results in a request to remove the fixture, which may entail a costly and difficult diversion of the route.

Underground lines possess the advantage of immunity from damage due to storms, and it is from this point of view that most of the great telegraphic centres are being linked together by underground routes. Upon the other hand, the underground route has dangers of its own, for, whenever the streets are taken up, there is the possibility of damage due to carelessness or accident. Moreover, a general fault due to the entrance of water into a cable cannot be remedied with the speed that characterizes the repair of an open line breakdown.

Where a very considerable number of wires is required an underground route is less costly than several open ones. Where iron poles are to be used the cost of the underground line with 2-inch pipe becomes less than that of the open line when the number of wires exceeds about thirty.

TIMBER.

The supply of round telegraph poles is obtained from Scandinavia, Finland, and part of Russia, and the poles are cut from red fir-trees. For special purposes, such as square terminal poles, American pitch pine is also employed, but the cost is considerably greater than that of fir, owing partly to the fact that the huge demand for the latter enables the most favourable conditions for cheap transport to be met, and partly to the greater cost of the timber itself.

The use of iron poles is avoided wherever possible owing to their extreme costliness, which amounts to from four (in the case of long heavy poles) to eight (for light poles) times that of the corresponding wooden poles.

The timber selected for telegraph poles should be quite sound and hard grown (that is, with the annular rings closely pitched), straight, and free from large or dead knots. The trees should be felled between the 1st of November and the 28th of the following February, when the sap is in the roots. The natural butt of the tree should be left, but the branches and the bark, with all the adhering soft wood, removed, so as to leave a clean, hard, smooth surface. During the process of shipping, etc., the poles must not be left in water for more than seven days.

When creosoted poles are to be stored they may be piled together as closely as is desired, but the bottom poles should be raised a few inches above the ground by suitable supports. Timber which has not been subjected to any preservative process should invariably be stacked in such a way as to provide a perfectly free air circulation to every part of the wood.

PRESERVATIVE PROCESSES.

Wood is subject to deterioration by decay, which may be caused by dry or by wet rot. The former is caused by a species of wood fungus which in time reduces the wood to a fine powder. Since this effect only occurs in very enclosed places where there is no circulation of air, telegraph poles are entirely free from it. Wet rot is, however, of a far more serious character, and a pole which had not been subjected to any treatment would not last more than five or six years—possibly even less. The fermentation of the sap will in time reduce the interior of the pole to a pulpy condition, and, finally, instead of a solid pole nothing more than a shell remains. This state of affairs is readily detected by the hollow sound resulting from a blow with a hammer. The rotting of the pole at the ground-line (frequently termed the "wind and water" line) is of far more frequent occurrence, and is mechanically produced by the continual alterations of temperature and moisture. The temperature above the ground-line is higher than that of the soil, and thus moisture is drawn up each fibre of the wood. This moisture then expands, bursts its cell, and finally escapes as vapour. Wood is extremely durable when kept continuously dry or continuously wet, but is not so when the conditions alternate as rapidly as is the case in this country.

With pitch pine poles the timber is thoroughly seasoned, *i. e.* the sap is slowly dried out under conditions unfavourable to fermentation, secured by giving a good air circulation to *every* part of the wood. Charring the butt to a height of a foot above the ground line by slowly roasting it over a fire and then well tarring it with a mixture of Stockholm tar, coal tar and slaked lime proves quite sufficient for this class of timber. The effect of the process is to exclude moisture from the wood, and, with the exception of painting, no other treatment is adopted in this case.

Every other type of timber is subjected to one or other of the various preservative processes. Of these, creosoting is by far the most efficacious, but care must be taken that the wood is perfectly dry before being treated, otherwise more harm than good results. The life of a pole when properly treated is upon the average in excess of thirty years.

The creosoting process formerly used consists in injecting creosote into the wood by a process of vacuum and pressure. The quantity of creosote to be injected varies, according to the specifications of different administrations, from 8 to 12 lb. per cubic foot for telegraph poles, the Post Office specification being 10 lb. to 12 lb. The poles to be treated are placed in a closed cylindrical vessel, an air-pump is set to work, which produces a vacuum in the cylinder, opens the pores of the timber, and, to some extent, serves to draw out the moisture. Creosote, heated to a temperature of from 100° to 120° F., is then introduced into the cylinder, the air-pump is stopped and the pressure pumps are employed to force the creosote into the wood.

This process is most satisfactory when applied to well-seasoned and perfectly dry timber, since moisture would otherwise be driven into the heart of the wood. Seasoning is produced by allowing a perfectly free air circulation to every part of the timber for a lengthy period—not less than four months under favourable conditions is desirable. In order to save this delay and also to remove every trace of moisture prior to the injection of the creosote, S. B. Boulton devised the following method:—Creosote, heated to a temperature slightly in excess of 212° F., is introduced into the cylinder, and the air-pump, communicating with a dome fitted upon the top of the vessel, is set at work. It will readily be seen that, as the timber is thus subjected to a temperature above the boiling-point of water, any watery moisture contained within the pores of the wood is turned into vapour and is drawn off by the action of the air-pump. The creosote itself is not vaporized since its boiling-point is very much above that of water. When the last trace of moisture has been extracted, the pressure-pumps are employed to inject the creosote. Briefly then, the Boulton process consists in vaporizing the water in the timber by the heat of the creosote, and then withdrawing the vapour by the action of the air-pump before the injection of the creosote. The Post Office Engineering Department, in its treatment of telegraph poles, has availed itself of this simple and efficacious process for some years past, whenever it has been found necessary. It is rather remarkable that this example has not oftener been followed by civil engineers.

Considerable economy in creosote is effected by the recently adopted Rueping process, which is applied after the poles have been seasoned. Air is forced into the wood at a pressure of about 75 lb. to the square inch. Creosote is next injected under greater pressure, and then an air pressure of about 225 lb. is applied, thus driving the oil in to a considerable depth. When the pressure is released the compressed air in the interior of the wood drives out some of the creosote—an effect which is sometimes augmented by applying vacuum.* Only about 4 lb. of creosote per cubic foot is left in the timber.

Poles treated by this process have a dry brown surface of a pleasing colour and texture such as is only obtained with creosoted poles after they have been weathered for some years. The great advantage gained by this process is that poles so treated can be painted very soon after being taken from the creosoting cylinders, providing they are first wiped with a cloth and given two full coats of knotting.

Burnettizing consists in the injection of a concentrated solution of chloride of zinc.

Boucherizing consists in the injection of a concentrated solution of sulphate of copper.

Boucherizing is somewhat unreliable, and there is always a definite percentage of failures in which the life of the poles is but five or six years, but those which take the process well may be relied upon for a much longer period. The iron work fitted upon the pole is, however, more or less rapidly destroyed by the action of the copper sulphate. Burnettizing is, perhaps, more reliable, but the average life of poles so treated is not, upon the average, much in excess of twelve years. These two processes have the advantage that the poles can be painted, whereas an ordinary creosoted pole cannot, owing to the action of the creosote upon the paint in producing a curious ruddy-coloured covering which, unfortunately, never properly dries. The Rueping creosoting process is the one which is normally used; but where, prior to its introduction, in deference to local opinion, poles were to be painted, those treated by the Burnettizing process were employed.

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* "The Decay and Preservation of Timber," by W. H. Matthews, *P.O. Electrical Engineers' Journal*, Vol. IV. p. 305.

The various processes may be described as consisting in the injection of antiseptics or substances which oppose putrefaction. These substances combine with the sap to form insoluble compounds which cannot be acted upon by air or water. One great advantage of the creosoting process lies in the fact that, owing to its oily nature, it renders the pole perfectly waterproof.

The top of a wooden pole is protected from the elements by means of a galvanized iron pole roof of suitable size (8, 10, or 12 inches wide) fitted transversely to the line of the wires. The pole is cut to receive the sloping sides of the roof, which is secured by four 2-inch rose headed nails unless the pole carries a saddle wire, in which case the roof has suitable holes through which two 3½-inch coach screws and two nails supporting the saddle are passed.

In some few cases where ornamental poles are specified pole finials are used instead of roofs and are fitted with a dowel. In the case of square poles the top of the pole is lined with a suitable moulding so that the same form of finial may be employed as for round poles. These finials vary in height from 33 inches to 40 inches, and have precisely the same appearance as those used with iron poles.

ARMS.

The best material for arms is English, Irish, or Russian oak, but in times of scarcity Australian karri-wood is employed. The arms are pickled in a solution of green oil (a tar product) and copper sulphate.

Tubular iron arms, fitted with a strip of wood covering the upper sides of the arm between the insulator bolt holes, have also been used. The wooden insulating sleeve was necessary to prevent workmen seated on the arm in more or less damp clothes, from receiving heavy electric shocks when handling wires worked by a high voltage.

The standard arm is 48 by 2½ by 2½ inches for wires weighing 400 lb. or less per mile, and 48 by 3 by 2½ inches for larger wires, whilst 48 by 3 by 3-inch arms are used when the wires are terminated. The arms are bored and earth-wired with No. 12 annealed G.I. wire (Fig. 490).

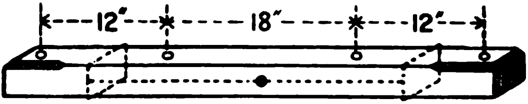

FIG. 490.—A 48-inch arm. The dotted lines represent the earth wire.

The arms are always fitted upon the London or "up" side of the pole. With the aid of an arm gauge the notches, having a maximum depth of 1½ inch, are cut so as barely to admit the arm, which is driven into the pole by means of a wooden mallet. In order to avoid rotting, the notches are painted over before the insertion of the arm with a mixture composed of one part gas tar and two parts of creosote by measure. In fact, wherever a pole is cut and the inner wood exposed a coat of creosote and tar should invariably be applied.

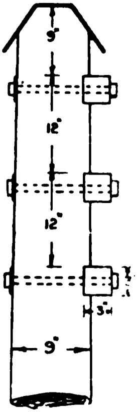

FIG. 491.—Spacing of pole fittings.

The centres of the arms are fitted 12 inches apart, and the first arm is placed 9 inches from the top of the pole (Fig. 491). The line wires attached to the four insulators carried by each pair of arms thus form a 12-inch square upon each side of the pole. It may perhaps be stated that the formation of a square is an essential feature of the symmetrical twist system of construction for telephone circuits.

For distribution lines for telephone subscribers' circuits eight wire arms, carrying 40 lb. bronze wires, are used, and in this case the 12-inch square is sacrificed to obtain a greater carrying capacity by the poles.

The arm bolts are of galvanized iron, each provided with a nut and two washers, and made in various lengths from 6½ inches upwards, with a diameter of ½ inch for the smaller, and ⅝ inch for the larger sizes.

INSULATORS.*

The qualifications of the material used for insulators may be stated as below :—

1. High specific resistance.
2. Homogeneous.
3. Not porous.
4. Should take a high polish.
5. Not subject to deterioration.
6. Readily mounted.
7. Preserves its form.
8. As slight an affinity for moisture as possible.
9. Tensile and compressive strength.
10. Toughness.

The only material which satisfies these conditions is porcelain, and then only when well burnt, so that, a partial vitrification having taken place throughout, it becomes homogeneous and non-porous. The other possible substances which could be used are given below, together with the reasons which make them undesirable.

Material.	Objection.
Ebonite	(5) Subject to surface deterioration.
Glass	(8) Hygroscopic, (10) brittle.
Brown earthenware	(4) Surface not so smooth as porcelain.

Glass is used to a very considerable extent in America, but this is largely because insect growth takes place beneath the sheds of any opaque insulator and so tends to bridge across the bolt and the outer shed. Again the climates of this country and America are of widely different character, and in comparing types of insulator this factor should always be taken largely into account.

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* The manufacture of porcelain is dealt with in *Electrical Porcelain* by H. W. Brady. Reprinted from the *Electrician* of May 29, June 5, and June 12, 1908.

The choice of the material for use in insulators is practically limited to porcelain and earthenware. The former is exclusively used where high insulation is necessary, but upon minor lines there is no objection to the use of brown earthenware. It has, moreover, the merit of greater cheapness, and forms a less conspicuous target for stone-throwing.

The factors which determine the ***design*** of an insulator are mechanical strength and insulating properties. The latter are secured (1) by increasing the distance to be traversed by a current leaking from the wire to the insulated bolt, (2) by reducing the section of the conducting film, (3) by the retention of a dry surface on one portion of the insulator, and (4) by securing that the general form of the insulator shall not help or retain deposits of dust, soot, etc., nor foster the growth of spiders or other spinning insects.

The insulator spindles or bolts are of steel; for heavy stresses and terminations a specially heavy form of spindle is employed.

Most of the earliest forms of insulator were of the fixed bolt type in which the cup was cemented on to the bolt. This type gives a very much lower insulation resistance than the screw-cup type, and involves the removal of the bolt from the arm whenever a damaged insulator has to be replaced.

The standard form of insulator is that designed by J. H. Cordeaux many years ago, and illustrated in Fig. 492. It is mounted upon a steel spindle the upper extremity of which ends in a flange and a coarse screw, whilst the lower part serves for securing the bolt to the arm. The cup itself is of porcelain made in one piece and having a coarse female screw for securing it to the spindle. The cup is screwed down on to the india-rubber or felt washer which is placed upon the upper flange of the spindle. This gives the arrangement a small amount of flexibility, which no doubt saves the cup from breakage in the event of sudden stresses, and it also serves to prevent fracture of the cup due to the differing coefficients of expansion of the metal spindle and the porcelain cup. The double shed secures a dry and comparatively clean part of the insulator, therefore increasing the resistance which a current encounters in passing over the surfaces from line wire to bolt. The outer shed in course of time becomes black by being coated with the solid matter (chiefly carbon) which the atmosphere contains. Also, the corrosion of the wire, if of iron, adds its quota to this deposit. The time taken for the deposit to accumulate depends entirely upon the character of the neighbourhood, but arrangements are made periodically to remove and cleanse the insulators.

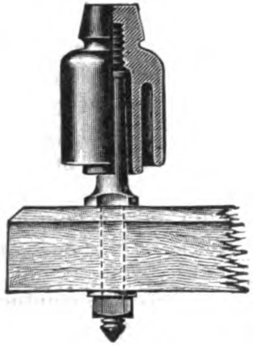
FIG. 492.—Cordeaux's double shed white insulator with steel spindle.

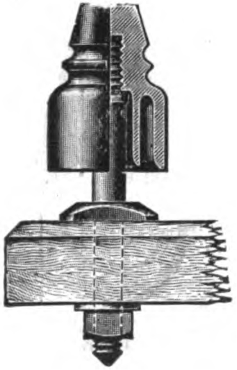
FIG. 493.—Post Office terminal insulator.

Where wires are terminated as at the junction of underground and open lines, or where a very sharp turn in the line occurs, terminal insulators are employed. These insulators are of the double shed screw-cup form, but are much heavier and stronger, and are provided with two grooves. The steel bolt is also heavier, with a broad flange, and projects further into the upper portion of the cup, which is so shaped as to keep the point at which the wires are attached near to the arm, thus reducing torsional stress upon it. These details will, however, be sufficiently apparent from a consideration of Fig. 493.

The ordinary standard spindle may be adapted to meet heavy stresses by the addition of a G.I. washer 2 by 2 by ⅛ inch placed between the flange of the spindle and the arm, thus increasing the bearing surface.

Where it is necessary to terminate heavy conductors the vertical spindle of the insulator tends to cant the arm. In order to avoid this difficulty "J" bolts fitted with screw-cups of the terminal form are frequently employed (Fig. 494). The advantage gained is that the stress is applied directly in the plane of the arm-bolt, and there is therefore no tendency towards canting. Moreover, the arms are in such cases invariably fixed upon the further side of the pole so that the stress is not taken by the arm-bolt. The bolt is of ¾ inch galvanized iron when used for heavy conductors, but a lighter form (⅝ inch) is frequently employed upon roof structures or where the conductors are of small gauge terminated upon 2½ by 2½-inch arms.

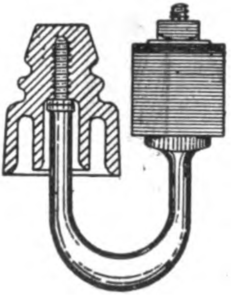
Fig. 494.—J-bolt and terminal insulator.

The terminal spindle is therefore only employed in those cases in which it is necessary to terminate wires upon both sides of the pole, as, for example, in the case of a route of open wires crossing a railway line. In every case in which the use of such a spindle would produce a torsional stress upon the arm J-bolts are invariably substituted.

The pothead insulator,* invented by T. F. Purves and J. Sinnott, provides the cheapest and most efficient method of connecting aerial wires to covered leads which has ever been devised. The connection between the open wire and the covered lead is made in a cavity formed at the top of the insulator (Fig. 495); this cavity is then filled with insulating compound and covered by a screw cap. In this way, a lead-covered cable may be carried up to the insulator, where the end is effectively sealed by the compound. Telephone subscribers' circuits are led in with lead-covered cable having 2-wire enamelled and cotton-covered 10 lb. conductors.

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* "Potheads and Pothead Insulators," by E. Gomersall, *P.O. Electrical Engineers' Journal*, Vol. I. p. 118.

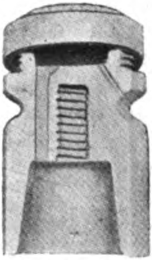

Fig. 495.—Pothead insulator.

The inconvenience and danger of using a heating pot in such places as the top of a pole or ladder led to the introduction of a compound* which is soft enough to be pressed cold into the insulator top and is not materially affected in consistency by changes of temperature met with in practice. It has a high insulation resistance when dry, and this is maintained when in contact with

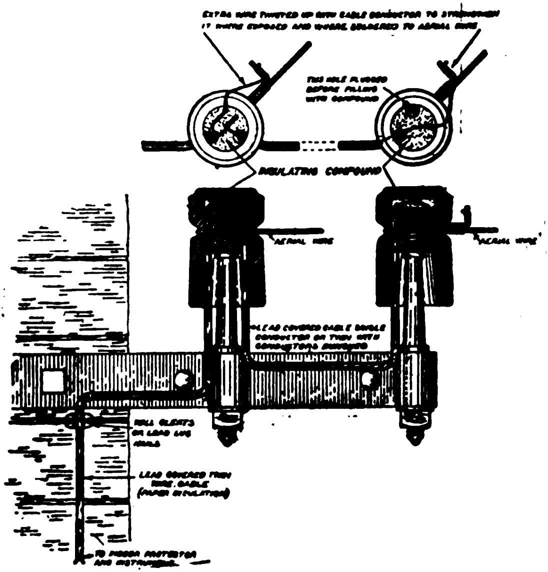
EXTRA WIRE TWISTED UP WITH CABLE CONDUCTOR TO STRENGTHEN IT WHERE EXPOSED AND WHERE SOLDERED TO AERIAL WIRE
THIS HOLE PLUGGED BEFORE FILLING WITH COMPOUND
INSULATING COMPOUND
AERIAL WIRE
AERIAL WIRE
LEAD COVERED CABLE SINGLE CONDUCTOR OR TWIN WITH CONDUCTORS BUNCHED
WALL CLEATS OR LEAD LUG NAILS
LEAD COVERED TWIN WIRE CABLE (PAPER INSULATION)
TO FUSES PROTECTOR AND INSTRUMENTS

Fig. 496.—Method of connecting a double wire circuit.

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* "Insulating Compounds," *P.O. Electrical Engineers' Journal*, Vol. VIII. p. 183.

water. Its composition is by weight 56% French chalk (magnesium silicate), 32% Palm pitch, and 12% coal tar.

The compound should be thoroughly pressed into the cavities of the insulators so as completely to enclose the bare wire joints, care being taken to see that the cavities are quite dry before it is put in.

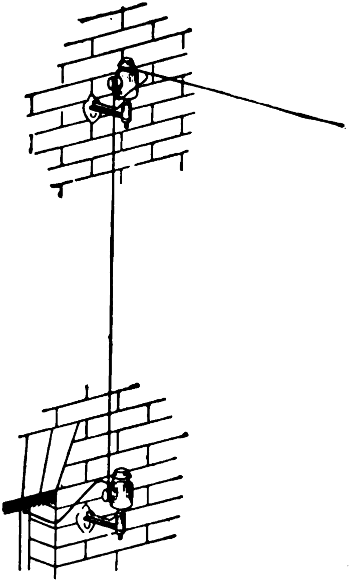

FIG. 497.—Leading-in by means of side-knob insulators.

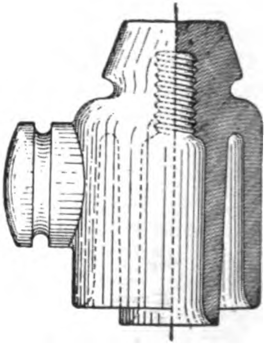

FIG. 498.—Side-knob insulator.

Recently, a lightning protector provided with a sealing chamber has been designed for use at the leading-in point in subscribers' offices. The twin wire cable from the pothead insulator to the protector is thus sealed at both ends. For a telegraph circuit a lead-covered cable having two 40 lb. conductors insulated with rubber is used. Where the length of lead is considerable and there are many wires, paper core cable and cable distribution plugs (*q. v.*) are employed.

The side knob form of insulator (Figs. 497 and 498) is in general use to reduce the length of covered wire required to lead a circuit into an office. An insulator of this type with potheading facilities is used for leading-in subscribers' circuits where the first point of attachment is far above the point at which the wires enter the building.

Yet another type of insulator may be mentioned, since it is being employed somewhat extensively upon minor lines where damage due to stone-throwing cannot be eliminated even by frequent prosecutions. The porcelain shed of the insulator is entirely covered by a brown enamelled iron hood, and although this reduces the insulation somewhat, it is not of serious consequence on minor lines.

Fuse insulators have already been dealt with (*vide* page 707).

It may be pointed out that insulators (known as "medium" and "small" insulators) of the same general pattern as that illustrated in Fig. 492 are made in smaller sizes for use on minor lines with double and quadruple cupholders and for 40 lb. bronze wires respectively. There is also a "small" insulator with two grooves for terminating 40 lb. bronze wires.

CHOICE OF MATERIAL FOR LINE WIRE.

The choice of the material for use as line wire is practically restricted to iron, copper, and bronze. Bronze can be used in smaller sizes than iron or copper. The breaking weight of a 40 lb. bronze wire is 197 lb., whilst that of a 70 lb. wire is 345 lb., or rather more than that of a 100 lb. copper wire. The resistance is, however, very much higher, an ohm-mile of bronze wire weighing 1820 lb. (see table, page 786). The 40 lb. wire is employed for telephone subscribers' aerial wires. It may be remarked that as the proportion of silicon or aluminium is increased the ductility and conductivity are reduced whilst the tensile strength is enhanced. Phosphor bronze wire has a conductivity equal to 40 % of that of copper with a tensile strength proportional to 80,000 lb. per square inch for even the finer wires.

For telegraph circuits two sizes of iron wire are employed, viz. 200 lb. and 400 lb., the former being used for minor circuits. The 400 lb. wire is the standard for all telegraph circuits which do not come under the headings of minor or very long high speed circuits. Iron wire is subject to deterioration, and when taken down it is almost valueless, whereas old copper wire is nearly as valuable as new. There is, however, a distinct difference in favour of iron between the cost of a 100 lb. copper and a 400 lb. iron wire, and it is to this fact that the continued use of the latter is due.

The resistivity of iron is over six times as great as that of copper, and therefore there is a decided gain from an electrical point of view in the use of 100 lb. copper wire in preference to 400 lb. iron.

The use of the lighter copper wires in place of iron results in an increase in the number of circuits which can safely be added to a pole line. Again, during storms, the lighter copper wires break instead of the poles, since the stress to which the pole is subjected is but a fourth of that resulting when a tree falls upon an iron wire line. It is far easier to deal with a breakdown in which the supports are intact than one where several poles are broken.

The weight of snow and ice which a wire will carry before breakage varies with the gauge of the wire—for instance, a 150 lb. copper wire would carry only one-fourth the weight of ice which a 600 lb. wire would safely bear if erected in a span of equal length. Since the quantity of ice which adheres to the wires is found, under like circumstances, to be practically the same with every gauge of wire, the light wires may be loaded up to, or beyond, the breaking point, whilst the heavier wires are but little affected. It is from this point of view that the diameter of open wires may not be reduced below a certain point. For main lines 150 lb. wire is usually the lightest type of conductor employed, whereas in towns and other more or less sheltered positions 40 lb. bronze wire may quite safely be utilized. Again, the same gauge of wire erected in 60 yard spans would safely carry twice the weight of ice per yard run as it would in 85 yard spans.

IRON WIRE.

The manufacture of the iron wire is a comparatively simple process. The pigs of iron are puddled in a furnace, hammered into a compact form, passed through a series of rollers which continually reduce the diameter of the wire, and finally through a number of dies of regularly diminishing size. The wire is drawn through these dies whilst cold, but the dies do not come into the process until the limit of the rolling mills has been reached. The wire is then thoroughly "galvanized" by passing the wire, after heating and chemical cleansing, through a bath of molten zinc. This process protects the wire from rapid oxidation and so lengthens its life. The outer layer of zinc becomes oxidized upon exposure to the elements, but as zinc oxide is insoluble this layer forms a protective coating which secures the iron from oxidation.

Before wire is accepted from manufacturers it is subjected to a series of tests which may be divided under three headings, viz. form, mechanical properties, and electrical properties. In the case of iron wire a test is also applied with the object of ascertaining if the galvanizing has been satisfactorily performed.

It is essential that the possibility of breakage due to defects in manufacture shall be carefully guarded against, and with this object the maximum tensile strength combined with ductility or absence of brittleness is specified.

Since maximum resistance per mile together with weight and gauge are set forth the specific resistance of the wire is specified by implication.

The various details of the tests will be apparent from the summary given below. It may be remarked that the tests are made upon samples chosen at random.

Form.—(1) The wire must be perfectly cylindrical and of uniform diameter. (2) It must be free from scale, inequalities, flaws, splits and other defects.

(1) This is measured by a micrometer at one or more points in every piece.

(2) (*a*) The wire is closely examined by the eye. (*b*) The absence of splits is determined by passing the wire over

four or more rollers placed in positions selected by the Inspecting Officer (*e. g.* as in Fig. 499), and is sufficiently stretched to remove all bends or sinuosities.

Ductility.—The wire is gripped between two vices, one of which revolves at a speed not exceeding one revolution per second, thus subjecting the wire to torsional stress. A straight ink mark is made upon the wire which, during the torsion, becomes a spiral mark upon the wire. The twisting is continued until the wire breaks, when the number of spirals counted must not be less than the number specified in the table.

Galvanizing.—A sample cut from any coil of wire at random is plunged into a solution of sulphate of copper saturated at a temperature of 60° Fahrenheit, and allowed to remain immersed for one minute. It is then removed and wiped clean. This process is performed four times with each sample of line wire, but only twice in the case of binding wire, without there being any sign of a reddish deposit of metallic copper upon the wire, which would be the case were the galvanizing too thin.

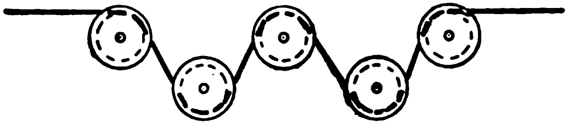

FIG. 499.—Arrangement of rollers for the testing of iron wires during manufacture.

The wire should be capable of being bent round rods of the following diameters without the galvanizing showing any signs of cracking or peeling off:—

For 800 lb. wire	2½ inch rod.
„ 600 lb. wire	2¼ „ „
„ 400 lb. and 450 lb. wire	1¾ „ „
„ 200 lb. wire	1¼ „ „

Tensile Strength.—The wire must be capable of lifting a weight equal to nine-tenths of the minimum breaking weight for the size of wire under test. The remaining tenth is added gradually in weight equal to at least one hundredth of the total breaking weight.

Electrical Properties.—The resistance of each test piece (minimum length $\frac{1}{30}$ of one mile) is reduced to the standard inversely as the square of its diameter and is calculated for a temperature of 60° Fahrenheit. In the event of dispute as to the diameter of the wire the test piece is weighed and the weight of one mile calculated. If the resistance per mile multiplied by the weight per mile exceeds 5328 the consignment is rejected.

GALVANIZED IRON WIRE.

Weight per statute mile.		Diameter.			Tests for ductility and strength.		Maximum resistance per mile of the standard size at 60° Fahr.	Limits of weight of each piece or coil of wire.
Standard.	Range allowed.	Standard.	Range allowed.	Approximate standard wire gauge.	Minimum breaking weight.	Minimum number of twists in 6 inches.		
lb.	lb.	mils.	mils.	No.	lb.		Standard ohms.	lb.
400	380 420	**171**	167 175	7½	**1200**	**24**	**13·32**	90 120
200	190 210	**121**	118 125	10½	**600**	**30**	**26·64**	40 65
60	57 63	**66**	64 68	16	Used only for binding and jointing	25 in 3 ins.	—	5 14

COPPER WIRE.

Form.—The wire must be perfectly cylindrical, uniform in quality, pliable, free from scale, inequalities, flaws, splits, and other defects. This is tested by micrometer and by visual examination.

Ductility.—(1) The wire must be capable of being wrapped in six turns round wire of its own diameter, unwrapped, and again wrapped, in six turns round wire of its own diameter in the same direction as the first wrapping without breaking.

HARD DRAWN COPPER WIRE.

Weight per statute mile.		Approximate equivalent diameter.		Approximate standard wire gauge.	Minimum breaking strain.		Minimum No. of twists.	Maximum resistance per mile when reduced to standard diameter.	Weight of each piece or coil of wire.
Standard.	Range allowed.	Standard.	Range allowed.						
lb.	lb.	mils.	mils.	No.	lb.			Standard ohms.	lb.
800	784 816	223½	221½ 226	4½	2,400	In 6 inches.	15	1·0984	100 140
600	588 612	193½	192 195½	6	1,800		20	1·4645	
400	392 408	158	156½ 160	8	1,250		25	2·1968	
300	294 306	137	135½ 138½	9½	950		30	2·9291	
200	196 204	112	111 113	11½	650	In 3 inches.	20	4·3936	75 130
150	147 153	97	96 98	13	490.		25	5·8582	75 120
100	98 102	79	78½ 80	14	330		30	8·7873	
182	—	(*25½*)	(*25* *26*)	7/19	580		60	4·9928	50 70
113	—	(*37½*)	(*36* *37½*)	3/18	350		50	8·1133	30 60

BRONZE WIRE.

40	39 41	50	49½ 50½	18	197	In 3 inches.	20	45·5	20 30
70	68 72	66	65 67	16	345		15	26	30 50

(2) The wire is gripped by two vices, one of which will be made to revolve at a speed not exceeding one revolu-

tion per second. The twists thus given to the wire are reckoned by means of an ink-mark, which forms a spiral on the wire during torsion, the full number of twists to be visible between the vices.

Tensile Strength.—Tests for tensile strength are made with a lever or other machine.

Electrical Properties.—The electrical resistance of each test piece or sample (minimum length $\frac{1}{80}$ mile) shall be reduced according to its diameter, and shall be calculated for a temperature of 60° Fahrenheit.

Where it is not considered necessary to insist on power circuits being guarded an insulated Bronze wire weighing 55 lb. per mile is sometimes used. The total weight of the wire and insulation is 134 lb. per mile, and the resistance approximately 29 ohms.

The insulation consists of a layer of impregnated paper, a spiral layer of cotton, a jute braiding and a protecting external covering of weather-proof composition.

This wire is not used in long spans. The length of span crossing a power circuit should not exceed 65 yards.

The wire is terminated at each end and the connection between the tail and the tailpiece of the bare line wire is made by means of copper sleeve joint.

BINDING-IN.

Iron wire is bound to the insulator with 60 lb. iron wire, of which four feet is required for 400 lb. wire and three for 200 lb. wire. The method of binding-in is shown in Fig. 500, and is preferable to the method formerly in use. The two laps of binding wire are taken over the

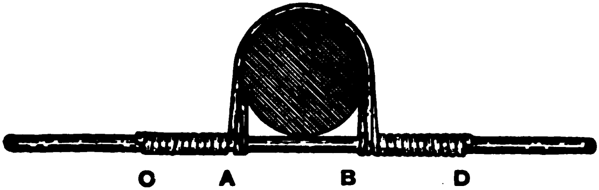

FIG. 500.—Method of binding-in iron wires.

line wire at *A*. The inner end is then taken round the neck of the insulator to the underside of the line wire at *B*, and after one complete lap is taken back round the insulator to *A*, and lapped on the line wire for about a dozen turns to *C*. The other end of the binding wire is taken from the under side of the line wire at *A* round the neck of the insulator to the upper side at *B*, and similarly lapped over the line wire to *D*.

Copper wires are secured to the insulators by binders and tapes. The binder consists of a round copper wire of suitable size with flattened ends. The tape is 47 mils. thick, is tightly lapped round the line wire with the aid of a pair of tongs having roughened jaws, and serves to prevent chafing due to the swinging of the wires under the influence of wind. The arrangement is shown in Fig. 501. In the event of the line wire breaking in the span the binder holds the wire quite securely, and prevents it from running back. It is, however, essential that the binder should be lapped round the wire in opposite directions upon either side of the insulator. The first two turns of the binder round the line wire and tape are formed by the round portion of the binder. The dimensions of the tapes and binders used for the various types of line wire are given on next page.

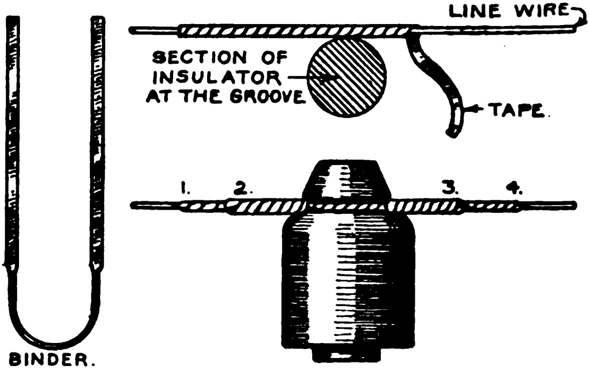

FIG. 501.—Method of binding-in copper wires, tapes, and binders.

Weight of wire per mile.		Length of binder.	Copper tape.		
Line.	Binder.		Length.	Width.	Thickness.
lb.	lb.	Inches.	Inches.	Inches.	Mils.
800 600	400	23	24	$\frac{1}{4}$	28
400 300	200	$20\frac{1}{4}$	22	$\frac{3}{16}$	24
200 150	150	17	18	$\frac{5}{32}$	22
100	100	17	18	$\frac{5}{32}$	22

Bronze wires are bound in with copper binding wire 40 lb. for 40 lb. bronze and 50 lb. for 70 lb. bronze wire.

The Bullers' clip (Fig. 502) is a recent innovation designed to replace the tape and binder method of securing the line wire to the insulator. The copper clip is passed round the groove of the insulator, and over the line wire is placed a U-shaped copper sheathing having its ends turned slightly outwards so that when the two wedges are driven in with the aid of the special pliers (Fig. 503) the line wire is pulled up the sheath. The sheath tends to arrest or damp any vibration of the wire and thus presents a definite advantage. The device is fixed and removed more quickly than a tape and binder, and is quite independent of the skill of the workman, but the arrangement is somewhat more costly than its older rival. The wedges used may be split so that the ends may be extended when placed in position;

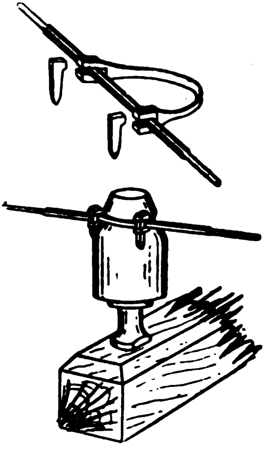

Fig. 502 —Bullers' clip.

but experience has shown that this precaution is unnecessary. It may be added that a special form of clip has been designed for terminating a line wire.

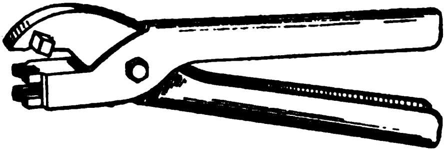

FIG. 503.—Pliers for use with Bullers' clip.

JOINTS.

The form of joint used for line wires is of the well-known Britannia type, but the ends of the conductors are nicked and broken off before the three turns of binding wire are applied to each single conductor. For jointing iron wires 60 lb. G.I. is used and for copper wires 50 lb. tinned copper wire. The wires are lapped as shown (Fig. 504) and soldered, care being taken not to apply any more heat than is necessary so as to avoid annealing the wire. The flux employed is known as Baker's soldering fluid, and to secure a satisfactory joint the wires must be cleaned with sandpaper before jointing is attempted. In the case of copper wires especial care is requisite in solder-

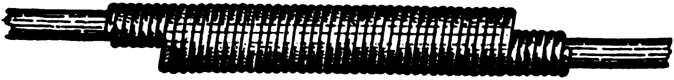

FIG. 504.—A joint in the line wire.

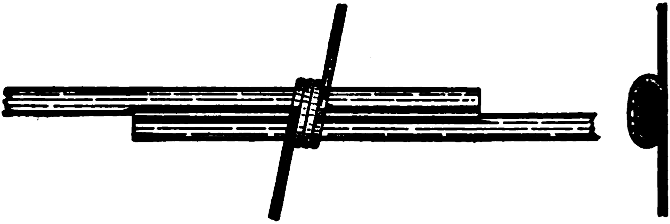

FIG. 505.—Method of jointing large conductors.

ing, and the joint should be allowed to cool gradually, and should never be chilled by placing it in water. The joint is then black-varnished in order to prevent electrolytic action between the line wire and the solder.

For large conductors such as 600 lb. and 800 lb. copper or iron wire two pieces of binding wire of the same material are placed in the spaces between the conductors in order to ensure a solid joint. This is illustrated in Fig. 505.

Defective joints, due to carelessness or lack of cleanliness, cause considerable trouble in the few cases where they exist.*

Twisted sleeve joints † (Fig. 506) are made on Copper and Bronze wires up to 150 lb. weight per mile. The ends of the wires are first cleaned and then placed side by side in a copper sleeve.

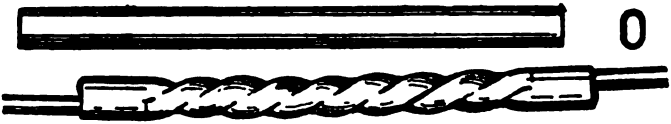

FIG. 506.—Copper sleeve joint.

The ends of the sleeve are then gripped by jointing clamps, and one of the clamps is revolved until a certain number of twists are given to the joint. The number of twists depend on the weight or size of the conductors, 5 turns being given to conductors up to 100 lb. and 6 for 150 lb. conductors.

A shorter sleeve is also employed for connections where there is no longitudinal stress, *e. g.* in connecting together the two sides at a termination, or for connecting open and covered wires. The sleeve joint has the advantage that time is saved by the absence of the necessity to solder the joints, and, moreover, there are many occasions when the sleeve joint can be made and the necessity for a subsequent visit with soldering materials is avoided.

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* Water enters the joint, and its resistance is not only high but is variable, and upon telephone circuits noises are at once produced. Since the defective joint may occur in the centre of a span it is only possible to trace it by a series of localization tests.

† Poole's *Telephone Handbook*, p. 354, from which Fig. 506 is taken.

EARTH WIRING.

In order to prevent current leaking from wire to wire via the insulators and arms and also to provide a lightning conductor every pole is "earth-wired." The arms are earth wired, as shown by the dotted lines in Fig. 490, the arm-bolt making connection with the wire when fixed in position. A 400 lb. G.I. wire is fitted to the side of, and is looped at right angles around, but it is not soldered to, the arm bolt; it is thus clamped between the bolt-head and the washer which is interposed between the bolt and the back of the pole. The upper end of the wire projects above, but should not make contact with, the pole roof, and acts as the point of the lightning conductor, whilst the remainder of its length is stapled down the pole to the butt, on the bottom of which it is stapled in two or three turns in the form of a volute. In all ordinary soils this provides a sufficiently good earth for the purpose, but in rock, or upon viaducts, it is better to omit the earth wire unless a special wire well earthed at the ends of the sections is provided for linking up the whole of the earth wires.

With the poles and arms earth-wired the current which escapes over the insulator to the arms is provided with a path direct to earth and therefore does not leak on to other circuits. Without this provision wires which occupy the same relative positions upon the arms for very considerable distances exhibit partial contact during wet weather. It is true that earth-wiring reduces the insulation of the circuits, but it is preferable to do this rather than to have even one-tenth part of the current so lost making its appearance upon other circuits.

In neighbourhoods where iron wire will not last, old copper wire, secured by copper staples, is frequently used for earth-wiring, but owing to the extra cost this course is only adopted where it is imperatively necessary. It is moreover desirable to groove the poles to receive the wire for at least 6 feet above the ground-line, thus rendering it difficult for the wire to be stolen.

DIMENSIONS OF POLES.

The length of the poles required to erect a given line is determined by the obstructions encountered *en route*, but with the qualification that the lowest wire upon the line, when carrying the maximum number of wires for which it is designed, shall not be less than 12 feet from the ground upon country roads, nor less than 20 feet at road-crossings, or over railway lines. In villages or small towns the lowest wire should be given a greater elevation in order to secure immunity from wilful damage, and also to keep the wires above the top windows of the houses which they pass. It is therefore necessary to determine the number of wires which the line will ultimately carry in order to decide the height of the timber.

The diameter of the pole is determined by its length and the maximum wind pressure to which the structure, with its ultimate number of wires, is likely to be subjected. The wind pressure is made up of two parts, that acting directly upon the pole itself and that exerted upon the wires which it carries. These points will, however, be separately dealt with later.

In order to meet the varying requirements three classes of poles are used and are respectively known as light, medium, and stout poles. The type to be used is fixed by the *ultimate* number of wires which the line will be required to carry [*]:—

Light poles (70 yard spans) up to 8 100lb. or 16 40lb. wires
Medium „ (66 yard spans) up to 16 100lb. or 24 40lb. „
Stout „ above

The poles are stocked in lengths varying from 16 feet to 85 feet.

The dimensions of a 30 foot, 40 foot, 50 foot, and a 60 foot pole of each class are given on next page.

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[*] The carrying capacity of the poles for wires of different gauge is readily calculated, since it is inversely proportional to the diameters of the wires.

Length of poles.	Sizes of light poles.			Sizes of medium poles.			Sizes of stout poles.		
	Diameter at top.		Minimum diameter at 5 feet from butt end.	Diameter at top.		Minimum diameter at 5 feet from butt end.	Diameter at top.		Minimum diameter at 5 feet from butt end.
	Minimum.	Maximum.		Minimum.	Maximum.		Minimum.	Maximum.	
ft.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.
30	5	6	7¼	6	7¼	8¾	7½	9½	10¾
40	5	6½	8	6	7½	9¾	7½	9¾	12
50	5¼	7	9½	6½	8¼	11½	7¾	10¼	13¾
60	5½	7¾	11	7	8¾	13¼	8	10½	15½

The distances between the poles vary from 60 to 80 yards, according to the type of line. For minor lines with from 1 to 4 100lb. wires 80 yards (22 poles per mile) is the standard span, but upon important routes 60 yard spans (30 poles per mile) are adopted. These figures, however, represent the ideal conditions, but in practice many modifications are necessary. In constructing a route the way-leave question enters into the problem to a serious extent, and therefore an 80 yard span upon a heavy main line is by no means the rarity one would desire. Where staying facilities cannot be obtained it is often necessary to reduce the lengths of the spans so as to distribute the lateral stresses over a larger number of poles.

In extremely exposed positions it is sometimes necessary to reduce the length of the span from 30 to 40 yards in order to enable the line to withstand the winter storms.

DEPTH TO WHICH POLES ARE BURIED.

In ground of ordinary character poles are buried to a depth equal to one-fifth of their length, subject to the qualification that no pole shall be buried less than four, nor more than six feet. In loose ground some extra depth is given, whilst in rock cuttings and ground where blasting is necessary the depth is reduced by one foot. Again, it may in special cases be necessary to set the poles in Portland cement concrete formed by mixing one part of

Portland cement, one part of river sand or screened gravel, and four parts of screened river ballast or broken brick or stone of such a size as to pass through a 1½ inch ring. These are matters which require experience, and no rule which fits every case likely to arise can be given. The pole should be buried to the minimum depth which will ensure that it will not be pulled over by the wires, and that in the event of an extraordinary stress the pole will be held by the ground until the breaking-point is reached.

The pole-holes, which should be made as narrow as possible and stepped as shown in Fig. 507, are dug in the line of the wires wherever possible in order that the pole may be bedded against solid earth, for no matter how thoroughly the earth which has been removed is punned when replaced it is never as solid as that which has remained undisturbed. In normal circumstances there is little or no tendency for the pole to move in the direction of the length of the wires, whilst there is only the rigidity of the earth in which the pole is buried to prevent its rocking laterally due to wind-pressure.

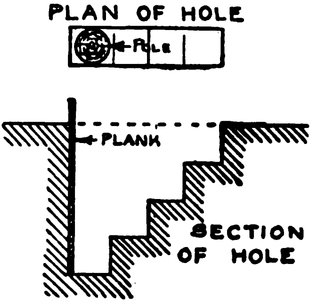


Fig. 507.—Plan and section of hole.

In marshy ground it is advisable to fix a block of wood at the butt in the same manner as with strutted poles. In some cases the pole is blocked at the base and also just below the ground line, large stones frequently being added in order to increase the bearing surface. These blocks may be formed from sound lengths of old poles, split down the centre, coated with creosote and tar mixture and secured to the pole by G.I. spikes. The flat sides of the two blocks should bed against the solid earth in the line of the wires and should be fitted upon opposite sides of the pole, the upper block being placed upon the side towards which the pole is likely to be displaced as the result of lateral stress due to the wires forming an angle at the pole or produced by the prevailing winds. The lower block prevents the pole from sinking, and at the same time keeps the base of the pole immovable owing to the comparatively large area which it offers to movement through the soil. In similar manner the upper block prevents movement at that point, so providing the rigid structure which it is the prime object of all good construction to secure.

Newly creosoted poles frequently exude a quantity of creosote after their erection, and in order to prevent it from flowing on to the pavement a depressed space is left around the base of the pole to allow the creosote to sink into the earth. In some cases it is also desirable to fit wooden laths around the lower part of the pole in order to obviate any risk of damage to the clothes of persons using the road, but the lagging is, of course, removed immediately the creosote has dried. Where necessary, this lagging may, however, in good class residential districts, be suitably painted to improve the appearance of the pole.

STAYS.

At angles in the line the poles are subjected to a lateral stress tending to pull the pole over in the direction which would eliminate the angle. The design of poles capable of withstanding this stress, in addition to that resulting during a gale, is quite impracticable on account of the size and cost of the structure necessary. Wherever possible stranded iron wire stays are employed, on account of their small cost and efficiency. The stay wire employed is of two types, viz. either four or seven strands of No. 8 galvanized iron wire. The breaking weight of the former is from 50 to 53 cwt., and of the latter 90 cwt. The type of wire chosen depends, of course, upon the stress which it is required to withstand; but this point is dealt with subsequently. For overhouse wire $\frac{7}{14}$ stay wire is employed.

The efficiency of a stay is in proportion to the length of the spread, and the stay has to bear the least stress when it makes an angle of 90° to the pole. To obtain a very wide angle would entail the use of a considerable length of stay wire, and it would therefore be more economical to provide two stays making a smaller angle with the pole; for ordinary lateral stays the spread should not exceed half the height of the resultant.

The function of the stay rod and bow is to connect the stay wire to the buried stay block, and to provide a means of adjusting the tension upon the stay wire. The upper end of the rod (Fig. 508) is provided with a screw thread and nut, which latter normally holds the stay bow in position. The stay wire is passed round the thimble upon the stay bow and spliced, and the nut is then tightened by means of a spanner. In order to prevent the nut from untwisting and so allowing the stay to become slack the base of the bow and the nut are cut so as to form a ratchet.

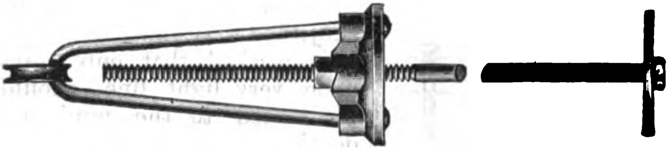


FIG. 508.—Stay rod and bow with ratchet nut.

The rods are made in three sizes, viz:—

	Breaking weight.
6 feet long and $\frac{5}{8}$ inch in diameter:—	95 cwts.
8 ,, ,, $\frac{3}{4}$,, ,,	142 ,,
8 ,, ,, 1 ,, ,,	260 ,,

The first-named size is only employed where $\frac{4}{8}$ stay wire is adequate, whilst the last-named is usually employed in connection with V-stays or other cases of excessive stress.

The stay rod is passed through a hole in the centre of the stay block, which consists of a creosoted block of redwood of one of the three sizes detailed below:—

Description.	Dimensions in inches.		
	Length.	Breadth.	Thickness.
Light	24	10	5
Medium	36	9	4½
Heavy	42	10	5

The large square washer which is placed between the bolt-headed end of the rod and the stay block serves to secure a satisfactory bearing surface against the wood. Without this washer the rod would, in course of time, work its way through the block.

The stay blocks are buried to a depth of from 4 feet to 6 feet according to the nature of the ground and the stress to which the support will be subjected. It may, however, be remarked that only stays upon very light lines should be buried to the minimum depth.

The hole for the stay (Fig. 509) should be undercut, and the earth removed to allow the rod to come into line with the stay should be as narrow as possible. In this way a bedding of solid earth for the block to pull against is secured, and, in ordinary circumstances, there is little chance of the stay being drawn or uprooted.

In rock a hole is sometimes drilled and an eye bolt leaded into it. The bolt is connected to a stay tightener with a racking lock nut.

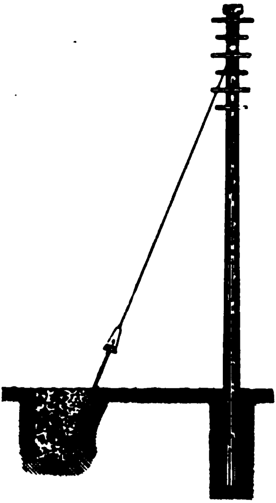


FIG. 509.—Pole and stay.

Where one stay is sufficient to take the stress exerted upon a pole this stay should be fixed at the centre of the stresses produced by the wires, or at the "resultant point," as it is usually termed. There will then be little or no tendency for the pole to buckle. The effects of disregard of this rule are rendered sufficiently obvious by Figs. 510 and 511.

The stay should act directly against the force exerted by the wires, and should bisect the greater angle made by the wires (Fig. 512).

The screw thread of every stay rod should be kept coated with a mixture composed of 45 parts of tallow, 45 parts of coal-tar, and 10 parts of mineral pitch, in order to prevent its destruction by rust.

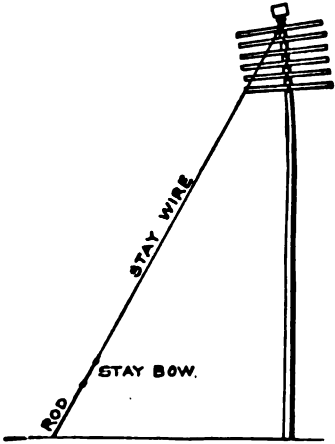


FIG. 510.—Stay attached above the resultant point.

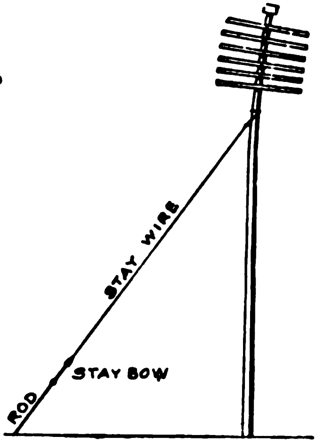


FIG. 511.—Stay attached below the resultant point.

Frequently it is necessary to fix stays upon the grass margin of a road, in the line of the kerb, or in other comparatively open positions, and, in order to avoid any

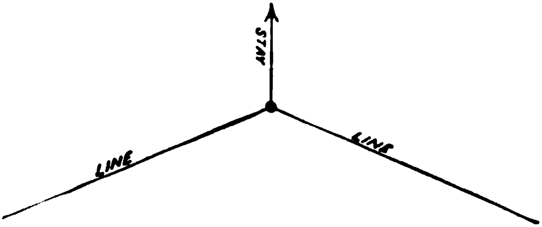


FIG. 512.—The stay should bisect the angle formed by the wires.

risk of users of the road colliding with them, it is essential that the stays shall be made as conspicuous as possible. A stay guard, used in these special cases, consists of a length of half round timber with the round side outwards, and lashed to the stay rod with G.I. wire, the flat side of the guard being recessed to receive the bow whilst the upper end finishes in a point. Such guards are frequently made by sawing old poles into suitable lengths (the guard should extend at least six feet above the ground) and then cutting the blocks down the centre.

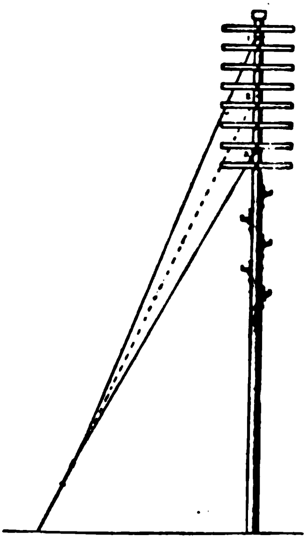


Fig. 513.—Pole with V-stay and fitted with 48-inch arms and pole steps.

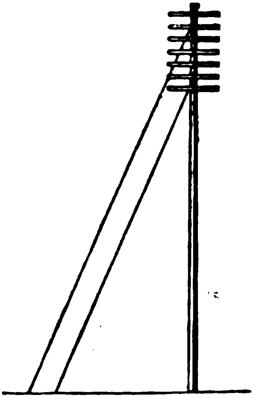


Fig. 514.—Parallel stays.

Where two stays are required on account of the heavy stress, they should be fixed at equal distances above and below the resultant joint, as indicated in Fig. 513. In this case a "V-stay" is shown, whilst in Fig. 514 two parallel stays are depicted. The former arrangement is in many cases to be preferred, and especially so where the line carries its full capacity of wires. The stay wire is in one continuous length, which passes round the thimble of the stay bow, where both sides are bound together with 200 lb. G.I. wire. When such a stay is fixed upon grazing land the two sides of the wire should be secured together at least 8 feet above the ground, so as to make it impossible for the animals to wedge their heads in the angle formed between the two sides of the stay.

The advantage of parallel stays lies in the fact that the second stay may be added without touching the first. Thus, in erecting a new line to carry 6 wires immediately, and, say 32 wires ultimately, the first stay would be fixed in the position which it should occupy when the line is full. When the need for the second stay arises due to the addition of wires it may be fitted without in any way interfering with the first.

With parallel stays care must be taken that the stays are accurately parallel, since nothing more unsightly than stays at differing angles to the pole can readily be imagined. This remark does not apply to a V-stay, since the line of the rod bisects the angle made by the two sides of the stay. If a V-stay is inadequate then parallel stays are used, but never a combination of a V-stay and a single stay.

The number of stays required to counterbalance the stresses exerted by a large number of wires at the first pole upon the line is occasionally so many that the resulting structure would be of a most unsightly character. In such cases 1½ inch round solid iron rods are frequently employed instead of the stranded stay wire, a malleable iron casting for clipping the pole being attached to the rod. A special spiked fitting is clipped on to the rod so as to prevent boys climbing up the stays, but the points are not sufficiently sharp to cause injury to cattle. With stranded stay wires barbed wire is often fitted at a height of not less than 10 feet above the ground-line.

The method of fixing the stay to the pole is to take the end of the stay wire twice round the pole, and to "make it off" upon itself. The first turn round the pole should be parallel with the ground line, whilst the second turn should come downwards in the direction of the stay. Where the two sides of the wire cross at the back of the pole a single staple is put over both.

The same form of splice, devised by M. F. Roberts, is made at the stay bow and at the pole. The loose end of the stay is unstranded, and the wires placed symmetrically around the part of the stay wire to which it is to be spliced. Each wire is successively bound round the stay wire, and the remaining strands thus:—

1st	wire	8	laps	around	main,	binding in	6	loose wires
2nd	"	8	"	"	"	"	5	"
3rd	"	7	"	"	"	"	4	"
4th	"	7	"	"	"	"	3	"
5th	"	7	"	"	"	"	2	"
6th	"	6	"	"	"	"	1	"
7th	"	6	"	"	"	"	—	"

The length of the completed splice is about 8½ inches. For ⅛ strand the four wires should make 8, 8, 7, and 7 laps respectively.

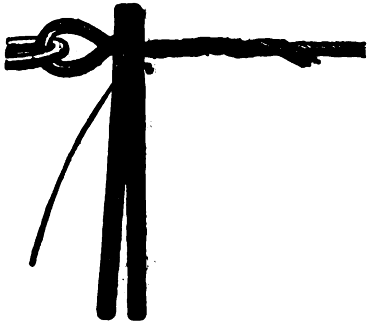


FIG. 515.—Roberts' stay splicing tool.

The work is considerably facilitated by the use of the Roberts' stay tool depicted in Fig. 515.

The nut of the ordinary stay rod is somewhat inaccessible, and to avoid this difficulty Bullers have introduced the modification shown in Figs. 516 and 517. The stay is tightened by turning the square head formed below the bow—the usual ratchet arrangement also is provided to prevent untwisting.

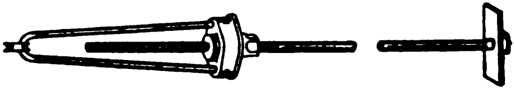


FIG. 516.—Bullers' stay rod.

Many arrangements to avoid the labour of making off the stay in the usual way are in use in America. Such a device, recently introduced by Bullers, is shown in Fig. 518 and replaces the upper part of the bow.

In no circumstances should a stay wire approach within 3 inches of any line wire, and where the circumstances

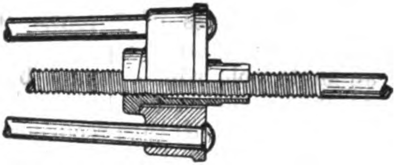


FIG. 517.—Sketch of Bullers' stay bow.

are such that this clearance cannot otherwise be obtained a ¾ inch G.I. stay crutch of the form shown in Fig. 519

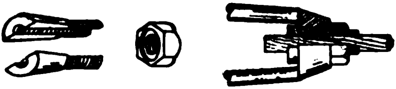


FIG. 518.—Bullers' gripper for termination of stay.

is fitted. The three legs are secured to the pole by means of coach screws and the stay bound in so as to prevent it from being jerked out of the fork by motion of the pole due to sudden gusts of wind. The crushing or breaking stress of a stay crutch itself is 5 tons.

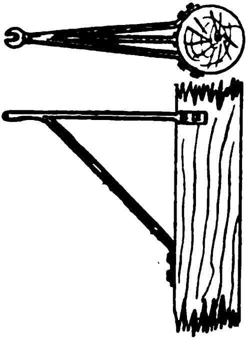


FIG. 519.—A top and a side view of a stay crutch.

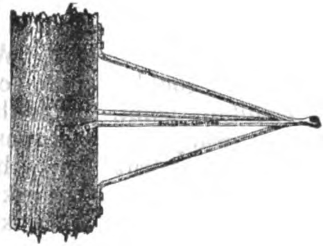


FIG. 520.—A pole spur.

A pole spur (Fig. 520) is frequently used in those cases in which the stay has to be fixed within say 12 or 15 inches of the pole. It is somewhat shorter than a stay crutch but is provided with an upper leg, and the ¾ inch size has a breaking stress of 7 tons. The fitting is occasionally employed to truss a pole, as for instance in the case of an angle pole which cannot be stayed. The pole may be blocked at the butt and just below the groundline (as previously described) thus securing, that the base of the pole shall be perfectly rigid. In order to strengthen and to prevent the pole from buckling, a pole spur is fitted half-way between the resultant and the end of the pole, and a length of stay wire is then secured to the pole at the resultant point, passed over the spur, and is terminated upon an ordinary stay rod passed through a hole cut in the butt of the pole so as to allow the surface of the washer to be covered by the butt.

STRUTS.

A stay may be defined as a support which is subjected to tensile stress, whereas a "strut" is primarily designed to withstand a compressive or crushing stress. When erected in the manner to be described a strut will also act as a stay, but its cost is considerably higher and its use is, in practice, restricted to those cases in which it is impossible to use a stay. With the old 24 and 33 inch arms a strut could usually be fitted at, or very near to, the resultant point, but with 4-wire arms, such as are now universally employed consequent upon the growth of the lines, the strut has to be fitted below the arms. This involves considerable risk in the case of heavy lines, since the pole is likely to break at this point during heavy gales. The danger can be obviated by fixing an outrigger and stay opposite the junction of the strut and the pole; but the arrangement is unsightly and not very efficient, since the stay-wire is likely to stretch under the enormous stress to which it is subjected. The better plan is to employ A or H poles in these cases.

The strut (Fig. 521) consists of a pole of somewhat lighter character than the pole to which it is to be fitted. The upper end of the strut, which should be at least

½ inch thick at the tip, is carefully scarfed to fit the pole, and a bolt (with nut) passing through both secures it in position. The pole itself should upon no account be cut to receive the strut, because, by doing so, it would be weakened at the very point where considerable strength is needed. The cut end of the strut should be painted with tar and creosote—a remark which applies to every cut of every description which is made in a pole, whether for scarfing, arming, or other similar purpose.

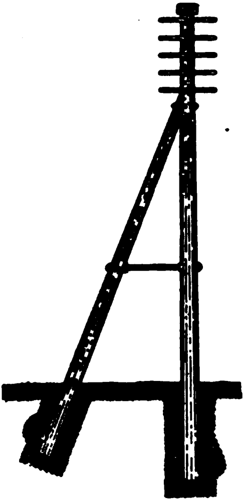


FIG. 521.—A strutted pole.

At a suitable point the pole and strut are rigidly connected together by a bolt and a length of 1-inch wrought-iron tubing. The bolt passes through the strut, spacing tube, and pole. The spacing tube banks against washers upon the undersides of the strut and pole, thus preventing the tightening of the bolt from buckling, or tending to buckle, the strut.

At each side of the pole a galvanized iron washer 3½ inches by 2½ inches by ¼ inch is employed, whilst the inner side of the strut is built up by means of tapered round washers so as to provide a perpendicular surface for the W.I. tube to bed against. Upon the outside leg of the strut a rectangular tapered washer, hollowed to suit the round pole, is fitted, and above this a round tapered washer for the nut of the bolt to bank against.

A strutted pole has a tendency to lift out of the ground by the sinking of the strut, and, in order to prevent this, the pole and strut are cut to receive a couple of stay-blocks, which are secured to them by ⅝-inch bolts and nuts.

In the very exceptional cases in which a strutted pole is in such a position that a horseman can ride between the pole and its strut the tie bolt is fitted at least 12 feet above the ground. Also, where a strutted pole or an A-pole has an opening which is not sufficient for cattle to pass through, but in which they might possibly get jammed, a vertical guard of creosoted timber 6 or 8 feet long with a pointed tip should be fixed in the centre of the aperture. A similar guard is sometimes required in the space between a pole and the wall where the space is restricted.

A-Poles.

For heavy stresses where a stay cannot be fixed A-poles (Fig. 522) are frequently employed. A long scarfed joint is made, and the two poles secured by a couple of ⅝-inch bolts, a tie-rod and tube, and a wooden block brace or transom. The poles are each reduced by not more than one-third of their diameter, and the cuts are covered with tar and creosote, so forming an air and water-tight joint and thus preventing premature decay. The tie-bar and tube are employed, and is fixed half-way down the pole, two round washers being used at the ends of the tube and two hollowed tapered washers against the outsides of the two poles. The transom consists of a block of creosoted wood, 7 or 8 inches square and of suitable length. This produces an extremely rigid structure, the efficiency of which is still further increased by the bracing effect of the arms which are each secured by two arm bolts, one through each pole. In very exceptional cases it may be advisable to also block the poles at the base and ground-line in the manner described in the case of poles in soft ground (page 795). In ordinary circumstances the space between the two poles should be about 12 inches at the ground-line, with a scarfed joint 8 or 12 feet long.

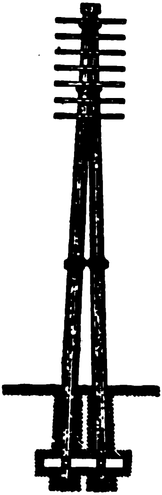


Fig. 522.—An A-pole.

With A-poles the gradually increasing width of the poles as arms are added fixes a limit to the number of wires which the pole will carry, but this difficulty is frequently minimized by the use of 57-inch arms. One earth wire only is required, and this is fixed in the least conspicuous position. To lateral stresses it is roughly five times as strong as a single pole.

H-POLES.

The H-pole, designed by M. F. Roberts, provides for six wire arms against the four wire arms of single, and A-poles. The structure is depicted in Fig. 523, from which it will be seen that the poles are connected by tie-bolts and spacing tubes together with truss-rods and rings. The object of the arrangement is to secure rigidity, and convert what would otherwise be two independent structures into the equivalent of a lattice girder. The arms each carry six wires, two of which are placed between the two poles. It should be noticed that the lowest tie-bar is connected with the wooden cross-piece, notched at least six inches in at the base of the poles, and that the top tie-bar is provided with large washers to prevent the top truss rods from damaging the poles by abrasion, consequent upon slight lateral motions under wind stress. Two earth wires are invariably fitted, one upon each pole.

Where the number of wires will not exceed 38, *i. e.* six arms and two saddle wires, medium poles are employed, and the redwood cross-piece or pole brace is 6 feet long by 8 inches square. Above this number, stout poles and a brace 8 feet by 8 inches by 8 inches are employed. The poles are 18 inches apart in the clear, and the rods and bolts are all of ¾-inch metal. The truss rods are, however, provided in 3 and 4 feet lengths, so that the trussing may be carried from 6 inches above the ground-line to any required height, but generally two sets only

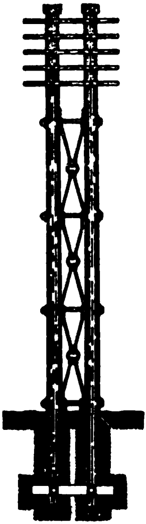


FIG. 523.—An H-pole.

are used. All the rods connected to any one ring must be of the same length, and where it is necessary to use sets of both sizes upon one pole the longer rods should be used at the upper part of the structure.

Here it may be convenient to point out that an H-pole line costs nearly three times as much as a single-pole line, and provides only for 50 % more wires. It has therefore a serious economical disadvantage when compared with two routes, each formed by single poles.

By using a long scarfed joint A-poles will meet the requirements in all the cases where stays cannot be used, and extra stability is necessary at angles. Where the stress due to an angle in the line is small, a strut is economically preferable to an A-pole.

SADDLE WIRE.

Many lines carry a "saddle" wire supported upon an insulator of the ordinary double-shed. The arrangement is illustrated in Fig. 524; but in this case the saddle is fitted with a "saddle stay" to prevent canting. This addition is, however, only necessary at angles in the line.

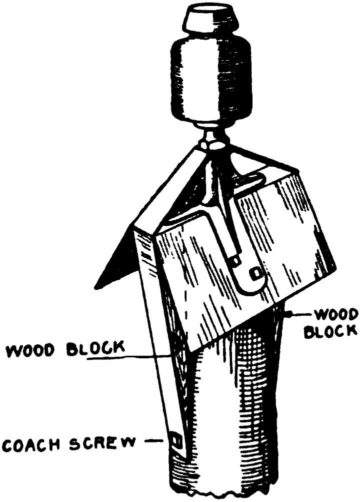


Fig. 524.—A saddle fitted with a stay.

The pole roof employed is of the "cut" type, and is secured by two 3½-inch coach screws and two 3-inch nails, which also hold the saddle. At the sides of the pole two hardwood wedges are used for the galvanized hoop-iron saddle stay to bed against. The stay is secured to the pole by two coach-screws, one upon each side of the pole.

When an A-pole is required to carry a saddle wire a hard wood cylindrical pin, termed a trenail, about an inch in diameter is driven through both poles, parallel with the arms and directly below the apex of the roof in such a manner that the coach screws securing the saddle in position shall enter the trenail.

POLE-STEPS.

In order to avoid the use of very long ladders and to save climbing it is usual to fit pole-steps upon all long timber. On country roads the lowest step is fixed 24 feet from the ground, so as to render them inaccessible to mischievous persons. The method of fitting the steps will be apparent from a consideration of Fig. 513, three coach screws being employed for securing the steps to the pole. The distance between the steps upon each side of the pole is 3 feet and between two consecutive steps upon opposite sides of the pole 18 inches.

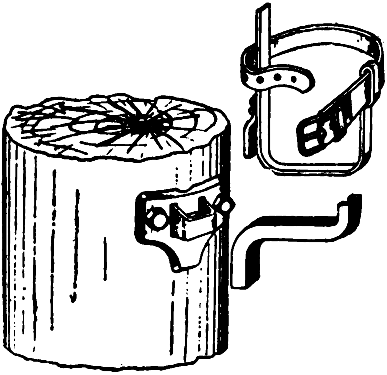


FIG. 525.—Bullers' pole steps and climbing irons.

In the case of painted poles in high-class residential districts the presence of the ordinary type of pole-step renders the structures somewhat unpleasantly conspicuous, and to meet this objection Bullers have introduced the arrangement shown in Fig. 525. It consists of a bracket into which steps can be fitted when necessary, or with the special climbers the pole may be ascended without them. The ordinary spiked climbers tear the poles and leave a series of unsightly holes and scratches where the paint is removed.

IRON POLES.

It has already been pointed out that the cost of iron poles is several times as much as that of wooden ones, and therefore their use is restricted to the utmost extent. There are, however, cases in which local authorities specially desire the use of iron in preference to wood, and where the streets are of a busy character or in high-class residential districts, the request is occasionally granted. The diameter of an iron pole is less than that of a wooden pole of the same height and strength. It is scarcely possible to describe a telegraph pole as ornamental, be it of creosoted or painted wood or of iron, but, as with electric tramways and street lighting, it is necessary to sacrifice appearance for the common good.

Iron poles are divided into five classes, designated light, medium, stout, extra stout, and heavy, which are respectively designed to carry 8, 16, 24, 32, and 40 wires, with a maximum height of 45 feet above the ground-line.

The Bullers' pole, which has been adopted by the Post Office, consists of a cast-iron base, into which is fitted the wrought steel pole formed of either three or four tubes jointed together. In every case the first two sections consist of parallel tubes, whilst the last section is generally tapered. Each joint occupies a space of one foot, hence two 11-foot parallel tubes and one 16-foot tapered tube forms a pole 35 feet long (1 foot of the first tube in the socket of the base, 1 foot of second tube within the first, and 1 foot of the third tube within the second). The tubes are interchangeable, and from the fifteen types shown in the first column the various poles detailed in the second may be formed by jointing the tubes as indicated by the third column. The distinguishing figures and letters employed serve merely to correlate the two tables and at the same time to emphasize the general scheme of the design.

The carrying capacity is subject to the qualifications that light wires, preferably 70 lb. bronze, 100 lb. copper, or at most 150 lb. copper, wires are employed, and that, since the positions are usually such that stays cannot be fitted, there shall be no difficult angles.

DIMENSIONS OF WROUGHT-STEEL TUBES.

Parallel tubes 11 feet long.			Tapering tubes.				
Distinguishing number.	Diameter in inches.	Thickness of metal in inches.	Length in feet.	Diameter in inches, tapering. From	To	Thickness of metal in inches.	Distinguishing letter.
1	$8\frac{1}{4}$	$\frac{3}{8}$	16	$6\frac{3}{4}$	$5\frac{3}{4}$	$\frac{7}{32}$	A
2	$7\frac{7}{16}$	$\frac{5}{16}$	16	$6\frac{3}{16}$	$5\frac{3}{8}$	$\frac{1}{4}$	B
3	$6\frac{5}{8}$	$\frac{1}{4}$	16	$5\frac{3}{4}$	4	$\frac{3}{16}$	C
4	$6\frac{3}{16}$	$\frac{3}{16}$	16	$5\frac{3}{8}$	4	$\frac{3}{16}$	D
5	$5\frac{1}{4}$	$\frac{5}{32}$	16	5	3	$\frac{5}{32}$	E
6	$5\frac{1}{8}$	$\frac{5}{32}$	11	$6\frac{3}{16}$	3	$\frac{5}{32}$	F
			11	$5\frac{3}{4}$	3	$\frac{5}{32}$	G
			11	$5\frac{3}{8}$	3	$\frac{5}{32}$	H
			11	5	3	$\frac{5}{32}$	I

DETAILS OF IRON POLES.

Type.	Height.	How formed.	Normal carrying capacity.	Length of base.
Light	30 feet	5, 6, I	8 wires	4′ 0″
,,	35 ,,	5, 6, E	8 ,,	4′ 0″
Medium	30 ,,	4, 5, 6	16 ,,	4′ 0″
,,	35 ,,	4, 5, D	16 ,,	4′ 0″
Stout	30 ,,	3, 4, 5	24 ,,	4′ 6″
,,	35 ,,	3, 4, C	24 ,,	4′ 6″
,,	40 ,,	3, 4, 5, 6	24 ,,	5′ 0″
,,	45 ,,	3, 4, 5, D	24 ,,	5′ 0″
Extra Stout	30 ,,	2, 3, 4	32 ,,	5′ 0″
,,	35 ,,	2, 3, B	32 ,,	5′ 0″
,,	40 ,,	2, 3, 4, 5	32 ,,	5′ 0″
,,	45 ,,	2, 3, 4, C	32 ,,	5′ 0″
Heavy	30 ,,	1, 2, 3	40 ,,	5′ 6″
,,	35 ,,	1, 2, B	40 ,,	5′ 6″
,,	40 ,,	1, 2, 3, 4	40 ,,	5′ 6″
,,	45 ,,	1, 2, 3, B	40 ,,	5′ 6″

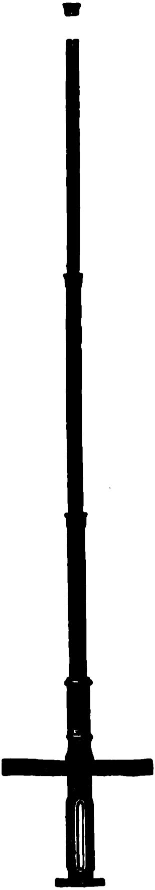
The joints between the sections of the pole are made by driving on jointing rings, so obviating the necessity for the "leaded" joints which were so conspicuous a feature of the older designs. The cast-iron base (Fig. 530) projects 1½ inches above the ground-line and prevents corrosion of the steel tube whilst giving a securer hold in soft ground. In order to improve the appearance an ornamental sleeve (Fig. 529), which extends 3 feet 6 inches above the ground-line, is placed above the base and, upon the top of the pole, a wooden finial is fixed.

A complete pole is illustrated in Fig. 526, and, with the aid of the two subsequent tables, the method of forming any of the poles from the 15 types of tube will be quite apparent, the various tubes being interchangeable.

The details of the Chambers' joint between successive tubes are illustrated in Fig. 527, from which it will be observed that the upper end of the tube is split longitudinally and that two wedge-shaped plates are riveted to the inner sides of the tube so as to form a support for the lower end of the upper tube which is cut to fit the fixed plates upon the lower tube. By driving the iron collar or jointing ring downwards the two halves of the split portion of the tube are brought into firm and rigid contact with the upper tube. The method of jointing the lowest tube to the cast-iron base is shown in Fig. 528. The upper portion of the base is shaped to receive the slightly tapered end of the lowest tube and to fit the wedge-shaped ring which is shrunk on to the tube a little higher up.

Another arrangement which has been designed provides for the substitution of an extra stout for a light pole without the necessity of disturbing the pavement. An extra stout base is used, and the diameter of the socket reduced by means of an "adapter" so as to receive a light pole. When, owing to increases in the number of wires, it becomes necessary to substitute an extra stout pole the adapter is removed and the new pole fitted within the base. Of course, a similar arrangement is needed to fill the space between the large sleeve and the light pole.

Bullers' tubular iron arms, of the pattern shown in Fig. 531, are used, and are fixed upon the pole by means of the clips. The 2-wire arms are 20 inches long, whilst the 4-wire arms are 44 inches in length, and provide for a space



G. 526.—An iron pole complete.

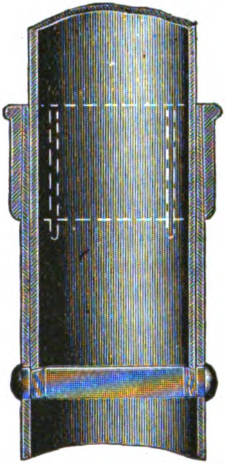


FIG. 527.—Method of jointing the wrought-iron tubes.

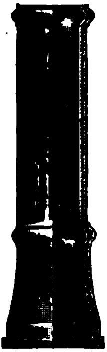


FIG. 529.—The ornamental sleeve.

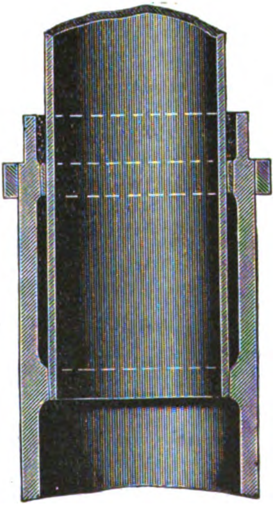


FIG. 528.—Method of fixing the bottom wrought-iron tube in the cast-iron base.

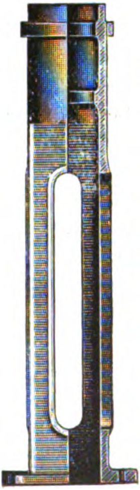


FIG. 530.—The cast-iron base which is embedded in the ground.

of 12 inches between the insulator spindle holes. As previously mentioned, a wooden strip is placed over each side of the arm and is held in position by the lower flanges of the insulator spindles.

Where an iron pole is used at the junction of an underground with an open line the wires are taken up the inside of the pole and pass out at the top through a curved ebonite tube of suitable dimensions.

Climbing clips or pole-steps of a special pattern are provided when necessary.

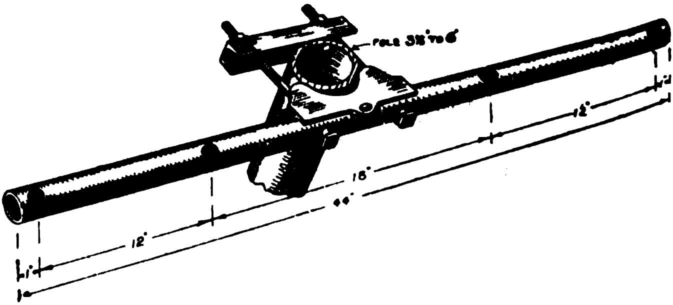


FIG. 581.—Iron arm used upon iron poles.

As a conclusion to the subject of iron poles it is necessary briefly to consider the method of erection. The base is set in the ground so that the uppermost portion projects 1½ inches above the ground-line. This brings the projecting flange which carries the ornamental sleeves ½ inch below the ground. In some cases the base is fixed upon a concrete foundation by means of bolts let into the concrete, and passing through the flange holes cast in the base, but this is not ordinarily necessary.

The various lengths making up the pole are put together on the ground, the malleable iron rings being driven home and a little thick paint or putty worked into the joints and slots to prevent rust discolouring the subsequent painting; before the bottom length of tube is jointed to the upper lengths, the ornamental sleeve is placed on it. The two grooves (opposite each other) will be found on the inside of top of sleeve to enable it to slide over the rivet-heads on the bottom tube. With the sleeve in this position the bottom length of tube is fixed to the upper lengths by the ring as already described. The sleeve is then lashed to the ring joint so that it may be out of the way whilst the pole is being erected.

The various tubes making up the pole having been put together, the bottom end of the pole is placed in the base with the assistance of a derrick or by other suitable means, special care being first taken to clean off the mixture of white lead and tallow from the machined surfaces (both inside and out) forming the bottom joint. The cast-iron sleeve is then lowered into position, and a man ascends to the top of the lower length, which will be about 10 feet from the ground-line, and, by tapping on the jointing ring, drives the ground joint firmly into its seat. If any of the joint rings have worked loose during erection they also should be driven home. The space round the top of the joint in the base should preferably be filled up with tow and putty, pitch or cement, to prevent water getting into the bottom joint, and the space between the tube and sleeve (at top of sleeve) should also be filled up in the same way to keep the sleeve in position.

When an "adapter" is used, in order to enable a pole to be used temporarily with a base and sleeve larger than standard, it should be placed in the base after this has been firmly fixed in the ground and the pole then placed into the adapter, the machined surfaces of the adapter and base being first carefully cleaned. The increased space between the bottom tube and top of sleeve is filled up by means of a cast-iron ring which is locked by giving it a quarter turn after the projections on same have passed down the two grooves in the sleeve.

It should perhaps be remarked that the final punning of the ground around the base will enable the pole to be set perfectly upright when the method of erection is as just described. In many cases the various portions of the pole are assembled upon the ground and then erected in precisely the same manner as wooden poles; the only possible objection to this course lies in the strains which the joints have to bear during erection.

In order to dismantle a pole the jointing rings are driven upwards, and the various sections can then readily be separated.

ERECTION OF A POLE.

Having discussed the various materials employed in the construction of a telegraph line it will now be well to consider the erection of the line. The stores are sent to various railway goods-stations *en route*, and a cartage contractor, assisted by a suitable number of men, is employed to lay out the stores in positions which will facilitate the actual work. Considerable economies can be effected by giving careful consideration to this matter.

The top end of the pole is raised from the ground on to a trestle, often formed by two crossed arms connected together with an arm-bolt at their centres and with a suitable length of spliced stay wire at their lower extremities. The notches for the arms are then cut in the pole, and the arms fitted with the utmost care. After the preliminary fitting, the arm is removed and the notch well painted with tar and creosote. When all the arms have been permanently fitted the pole is earth-wired and the pole-roof fixed. Whilst this work has been proceeding the hole will have been dug, and all the members of the party are then employed to raise the pole from the trestle, and the pole-cart is run in beneath the pole from the end of, and in the direction of the length of, the pole. The pole is then balanced upon the cart, and is wheeled along to the pole-hole, where the butt is lowered against the heavy wooden plank (see Fig. 507) which is placed against the end of the hole. This completes the first stage of the work.

A suitable number of thin cords or ropes, termed sash-lines, are next fixed to the pole (Fig. 532). A short ladder is then placed under the pole, and the end of one of the lower sash-lines is tied to a rung in order that the ladder may not fall when it is raised from the ground prior to taking a fresh position upon the pole. The ladders are frequently provided with spikes to prevent the ends slipping along the ground when the weight of the pole is encountered. Both ends are equipped with a wire rung at the top and bottom consisting of four 400 lb. G.I. wires stretching between the sides. The pole steps fitted upon nearly all long and heavy poles also serve to prevent any possibility of the ladders slipping upwards. Where there are no steps it is sometimes advisable to fix a few

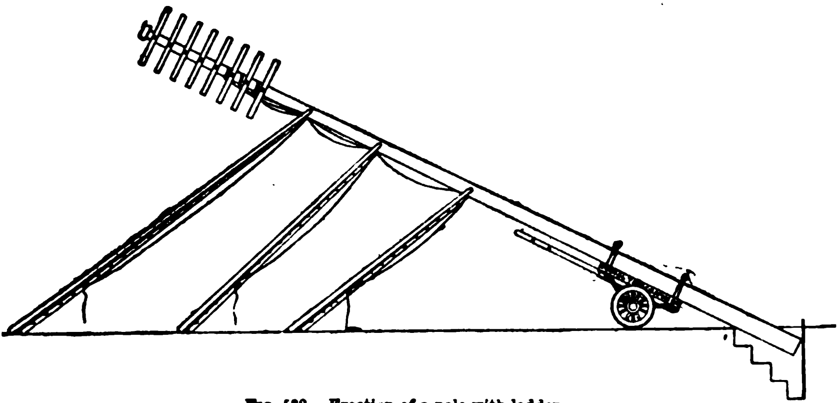


FIG. 582.—Erection of a pole with ladders.

upside down, say 4 feet apart, when erecting very heavy poles.

The pole is raised a short distance by the first ladder and a second is then inserted. This ladder takes the weight whilst the first ladder moves to a new position. In similar manner additional ladders are introduced until finally the pole is vertical. The number of ladders employed, like the number of men, varies with the weight and position of the pole. For very heavy timber ten to fourteen men should be provided. The foreman of the party directs the operations and ensures that only one ladder shall be altered in position at one time.

It should be pointed out that, during the earlier stages of the erection of the pole, the ladders should be splayed out upon either side of the pole so as to prevent the pole from falling laterally. In the later stages the sides of the hole into which the butt sinks deeper and deeper serve to prevent a lateral fall; but in all cases of doubt guy lines should be used with men stationed several yards away.

When the pole is up it is either strutted by a ladder banked beneath an inverted pole step or stayed with a rope connected to a crowbar driven into the ground. The pole is next turned so that the arms are in the correct direction. This may be accomplished by means of an endless loop of wire passing over a coach-screw driven into the pole and a crowbar as lever. A special tool has, however, been designed to meet this requirement.

The pole is carefully packed with large stones upon the sides, and the earth is shovelled into the hole in small quantities, and is thoroughly punned. This operation is of the utmost importance, for upon it largely depends the future security of the line. The pole hole should always be as small as possible, and where the pole will be subjected to lateral stress it should be given a set such that the stress will bring it to the vertical, but upon no account should the set exceed the amount necessary for this purpose.

Pole-lifters only, are now used for light and short poles, whilst a combination of lifters and ladders is employed for heavier poles. The lifters consist of light ash poles, 10 to 16 feet long, fitted with handles and furnished with a double pronged fork at the upper end. This fork is thrust into the pole to be erected, and the lifters are used in a manner identical with that previously described in the case of poles erected with the aid of ladders.

USE OF DERRICK.

Where the scantling is of a long and very heavy character, or where the position in which the pole is to be placed is an awkward one, it is frequently quite impossible to erect it in a manner previously described. Again, it occasionally happens that the pole is too long to be turned round in the road so as to get it into position for erecting in a space, entry, or street, at right angles to the road. There are also cases in which the pole has to be lifted bodily over a wall, building, or other obstruction. These are some of the conditions which render the use of a derrick essential.

In confined spaces, or with very long and heavy timber, the use of ladders is attended with some risk. Should a heavy pole come down, due to the ladders slipping, a fatal accident will almost inevitably result, and a derrick is used in every case of doubt.

The derrick consists of a short stiff pole, buried to a depth of at least two feet, to which an arm is fixed at the the top. Above this arm (Fig. 533) a sling-chain is placed round the pole, and to this is attached the treble block end of the main tackle. The pulling end of the 3-inch rope (3 inches is the circumference of the rope) is passed through a snatchblock hooked on a sling-chain at the base of the derrick. In order to prevent this chain from slipping up the derrick when a stress is placed upon the rope, 6-inch spikes are driven into the derrick. A couple of crowbars are driven into the ground and connected so that the rear bar forms a stay upon the forward one. To this a smaller set of luff tackle with 2-inch rope is attached by means of another sling-chain. The double end of the luff tackle is secured to the running end of the main set. The derrick is stayed in at least three, and preferably in four, directions to crowbars driven into the ground. Every hook is moused, *i.e.* bound across, so as to make it impossible for the chain to be jerked out.

The pole is wheeled to the post hole upon the pole cart, and a length of stout timber is placed against the back of the hole for the butt to slide down, and thus avoid it sticking into the ground at the back of the hole. Four sash-lines are attached to the upper part of the pole and are used to resist any tendency towards swinging. Finally the double block of the main tackle is attached to a sling-chain fixed just above the centre of gravity of the pole.

The pole is then reared by pulling the running end of the luff tackle. When the blocks of this tackle come together the running end of the main tackle is stoppered

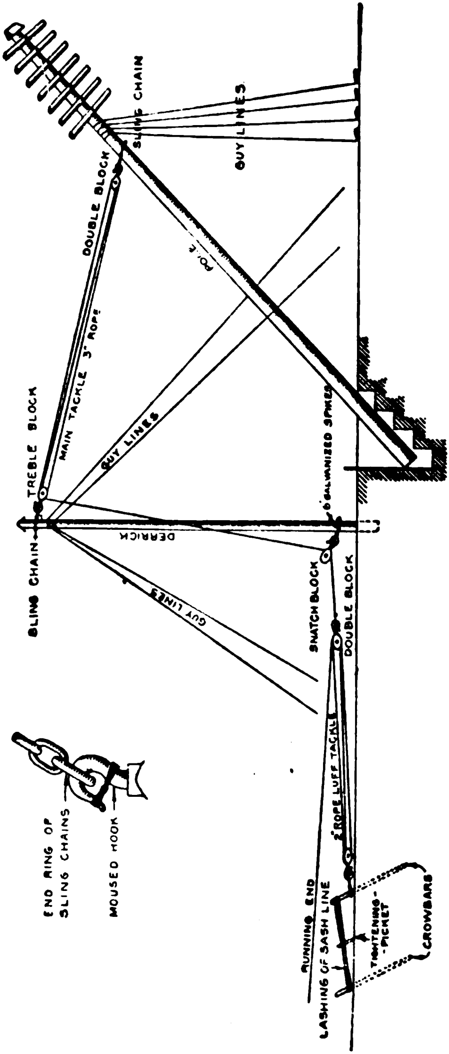


FIG. 533.—Erection of long and heavy poles with a derrick. (It is preferable to fix the guy lines above the sling chain.)

by means of a length of rope attached to the snatchblock sling-chain. This is accomplished by a very simple yet safe form of tie. The luff tackle is then extended and connected to the main rope close to the snatchbox. In this way the pole is gradually erected. In some cases a winch may with advantage be employed to replace the direct pull.

During the progress of erection a man is stationed at the hole with a punner or rammer with which the butt of the pole is eased down the plank at the back of the hole. As there is a heavy downward stress upon the derrick, it should rest upon a substantial block of wood when the ground is at all soft.

If the work is carried out with care there is no risk of accident.

WIRING.

The operation of running the wires next calls for attention. A coil of wire is placed upon the "drum barrow," which consists of a drum carried by a vertical axis mounted upon a light form of barrow. A brake is provided so that the revolution of the drum may be checked when necessary. The outer end of the coil of wire is then taken over the arms upon which it is to be erected. For this purpose light ladders are used and not pole-climbers, since the climbers score the poles with a series of unsightly marks. In fact, many gangs are not allowed to have even a single pair of climbers amongst their tools for this very reason.

The wire, having been passed over the arms of about eight poles, is then pulled up by a suitable number of men, whilst the final adjustment is made by means of a tension rachet and vice.

The tighter the wire is drawn up the smaller is the sag or dip, and therefore the smaller is the risk of contact. Upon the other hand the stress upon the wire may be made so great that the wire is liable to break. The ratio between the breaking stress of the wire and the maximum tension to which it is subjected is termed the "factor of safety." The factor of safety is least during very cold weather, when the wire has contracted to the maximum extent, and is greatest during very hot weather.

For straining the wire to the required degree, either tension ratchets and draw-tongs or draw-vices are employed. In the case of light copper or bronze wires the tension rachet is of the type shown in Fig. 535, the draw-tongs being illustrated in Fig. 534. The two sides of the draw-tongs are identical save that the diameters of the longitudinal grooves in the fixed block and the lever are, upon one side, suitable for gripping 70, 100, or 150 lb. wires, whilst those upon the other side are designed for 200 lb. wires, the object so gained being the avoidance of a multiplicity of different tools.

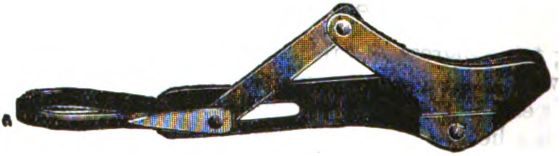


FIG. 534. - Light draw-tongs.

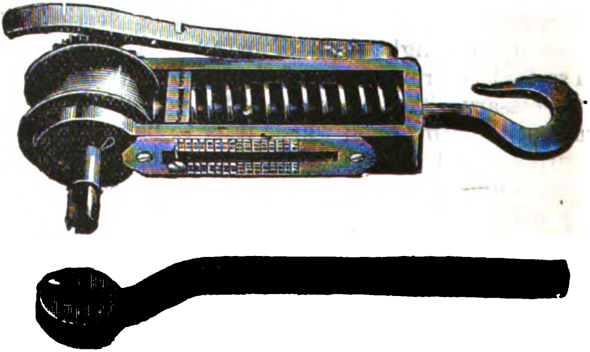


FIG. 535.—Tension ratchet and key.

The line wire is gripped about four feet in front of the arm by the tongs, which are joined to the tension ratchet by a keystone link. A length of six-strand steel wire with a globe insulator of a pattern similar to that used on electric tramways terminates in a scissors hook, which is fixed on the insulator spindle, the other end being passed through the hole in the drum of the ratchet. The insulation of the line wire by the globe insulator is of great advantage when repairs are being carried out on working wires.

By turning the ratchet-drum the wire is pulled up and the tension indicated upon the scale at the side of the instrument. The process is so obvious that further description is scarcely necessary.

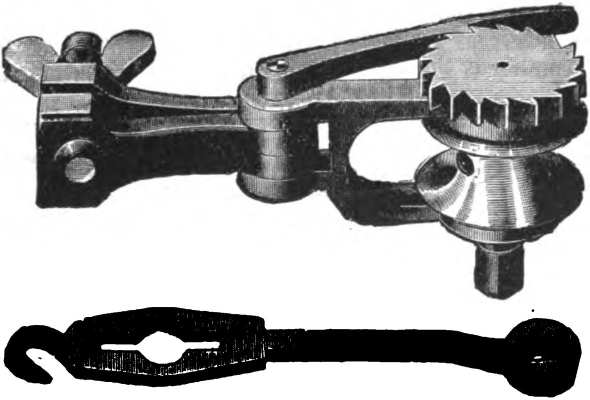


FIG. 536.—Steel draw-vice and key.

In wiring a new line the top or first wire dealt with is carefully strained by using tension ratchets which have very recently been checked for accuracy. The remaining wires are then pulled up to accord with the first by judging the dip by the eye. In the case of twisted telephone loops the accuracy of the adjustment may readily be judged by observing if the two wires of every pair appear to cross exactly at the centre of the span.

The draw-vice shown in Fig. 536 is very frequently employed in connection with iron wires, especially where additional wires have to be run and the stress is adjusted by observation of the dip.

For heavy gauge copper wires a larger form of tension ratchet and a specially designed draw-vice are employed, but the general principles involved are identical.

When the poles have been erected in wet weather it is desirable to delay the wiring as long as possible in order that the ground may have time to consolidate.

SAGS AND STRESSES.

The stress which should be put upon the wires when erected is determined by the necessity to avoid liability to breakage of the wire and on the other hand to minimize the danger of contacts. The tighter the wire is drawn the smaller is the dip and consequently the risk of contact less between the several wires. These opposing considerations led to the adoption of the rule that the tension should be such that at low winter temperature, 22° F., the stress should be equal to one-fourth of the breaking weight of the wire.

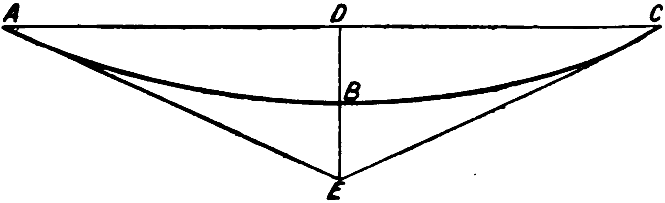


FIG. 537.—Line wire stress diagram.

In order to obtain the relations which exist between the stress, length of span and dip, it is necessary to employ the following well-known theorem in mechanics:—*If three forces acting at a point be in equilibrium they can be represented in magnitude and direction by the sides of any triangle which is drawn so as to have its sides respectively parallel to the directions of the forces.*[*]

Let *A B C* (Fig. 537) represent the parabola [†] formed by a telegraph wire stretched between two supports *A* and *C*. From *A* and *C* are drawn tangents to the wire which meet at *E*, *D E* being equal to twice the dip or sag *D B*. The stress on the wire is represented by $A\,E$, and $A\,D$ and $D\,E$ are respectively the horizontal and vertical components. The vertical component is obviously equal to the weight of half a span of wire $A\,B$. Calling this $\frac{W}{2}$ it will be recognized that $A\,E : D\,E :: S : \frac{W}{2}$ where S is the stress on the wire at A.

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[*] *Elements of Statics and Dynamics*, S. L. Loney, or any other work on Mechanics.

[†] Strictly, the wire hangs in a catenary curve.

But as the curve is extremely flat and $D\,E$ small $A\,D$ may be assumed to be equal to $A\,E$ (actually $A\,D = \sqrt{A\,E^2 - D\,E^2}$). The weight of the wire is equal to the length of the span $A\,C$ × weight per unit length,

$$\therefore \frac{l}{2} : 2d :: s : \frac{lw}{2}$$

$$s = \frac{l^2 w}{8d} \text{ and } d = \frac{l^2 w}{8s}$$

where l = length of span in feet;
w = weight of one foot of the wire;
s = stress in lbs.;
d = sag or dip in feet.

Example I. What is the dip on a 150 lb. copper wire erected in a 50 yard span with a stress of 120 lb.?

$$d = \frac{l^2 w}{8s} = \frac{150^2 \times \frac{150}{1760 \times 3}}{8 \times 120} = \cdot 6656 \text{ ft.} = 8 \text{ in. approx.}$$

Example II. What is the stress on a 200 lb. copper wire if the dip is 2 feet in an 80 yard span?

$$s = \frac{l^2 w}{8d} = \frac{240^2 \times \frac{200}{1760 \times 3}}{8 \times 2} = 136 \text{ lb. approx.}$$

Consideration of these relationships will show that (i) with a wire of any given material the stress is directly proportional to the weight per mile, (ii) the dip of wires of different gauges in a given span varies with the material but not with the gauge, (iii) that the dip and stress vary inversely, (iv) that the stress and the dip are each directly proportional to the square of the length of the span.

Since the breaking weight of a wire is directly proportional to its sectional area, it is also directly proportional to the weight of the wire per mile. Hence the dip of a wire varies with the material of which it is composed, but not with its gauge. This applies to any temperature, so that wires of differing gauges but of the same material may be erected upon a line without risk of contact, since the dip will be the same at every temperature.

In erecting iron and copper wires upon the same pole the effects of their differing coefficients of expansion are minimized by keeping the length of the span to 80 yards or under, but where this is impossible the stress tables are, to a small extent, departed from. It is preferable to run the iron wires at the top and the copper wires below for two reasons, firstly, because the iron telegraph wires are least subject to alteration by the addition of new circuits, and secondly, because the risk of contact is reduced.

The stress which is put upon a wire depends upon the material of which the wire is composed, the length of the span and the temperature. Every foreman is supplied with a thermometer in order that the actual temperature of the wire itself during erection may be accurately known. The length of the span is readily measured. With this information the stress to be put upon the wire is obtained from tables which have been previously prepared.

It has long been recognized that the tables which ignored the effects of elasticity gave too great a dip. The effect of elasticity is that the wire stretches when stress is put upon it, and so the increased tension due to the deposition of ice on the wire is partially compensated by the lengthening of the wire, which reduces the tension. Further, it will be recognized that as the temperature rises the wire expands and the tension is reduced. Consequently the elastic lengthening is reduced proportionately. When a wire contracts due to the lowering of the temperature the stress is increased, but this results in the wire stretching so that the alteration in dip is less than it would be were the wire inelastic.

The following factors of safety at 22° F. are adopted on various types of line:—

Copper wires on primary or secondary lines without bronze wires	4
Copper wires on exposed lines with average span of 30 to 40 yards	6
Copper wires on secondary lines carrying bronze wires	3
Bronze wires on secondary lines carrying copper wires	4
Bronze wires on local lines	3
Iron wire	4

Primary lines are defined as lines carrying main telegraph circuits or long-distance trunks involving the use of copper wire weighing 300 lb. or more per mile. Secondary lines carry chiefly junction circuits or short trunks. Local lines are those carrying mainly subscribers' circuits.

It may be of interest to indicate how the effects of elasticity and temperature changes may be calculated.*

If a wire L inches long having a sectional area of a square inch is stretched e inches by a stress of s lb. it has been proved experimentally that:—

$$e : L :: \frac{s}{a} : E, \text{ i.e. } e = \frac{Ls}{aE}$$

E is the Modulus of elasticity, and its value is equal to the stress per square inch of the section of the wire which would double its length if its elasticity remained perfect. It will be noticed that for a given length of wire the stretch is proportional to the stress, *i.e.* $\frac{e_1}{e_2} = \frac{s_1}{s_2}$ where e_1 e_2 s_1 s_2 represent the elongations and stresses in the two cases.

The length L_1 of the wire erected in a span of l feet with a dip of d feet is:—

$$L_1 = l + \frac{8d^2}{3l}$$

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* "Sag and Strain in Trolly Wires," by B. Hopkinson, *Electrician*, January 26, 1901; G. Lawrence, in *The Telephone Magazine* for September 1901; Poole's *Practical Telephone Handbook*, p. 363. An explanation

The factor of safety at 22° F. is specified, and this determines the stress at that temperature. The dip is then obtained from $d = \frac{l^2 w}{8s}$. For copper wire the coefficient of expansion k is ·000009 per degree F. Hence the increase in length of the wire from L to L_1 for a rise of t° above 22° F. is:—

$$L - L_1 = lkt$$

The change in elastic elongation is $\frac{l}{aE}(s - s_1)$ where s_1 is the new stress at $(22 + t)$°.

$$\therefore L - L_1 = lkt + \frac{l}{aE}(s - s_1)$$

The change in dip due to the elongation $L - L_1$ is obtained from

$$L - L_1 = \frac{8d^2}{3l} - \frac{8{d_1}^2}{3l}$$

Suitable tables showing the stresses to be put upon wires have been prepared. It may be said that the dip varies according to the temperature and length of span from a few inches to three or four feet—this latter value being exceeded only in the case of very long spans.

The following figures may be useful:—

k for iron = ·0000065 per degree Fahrenheit.
„ „ copper = ·000009 „ „ „
„ „ bronze = ·0000092 „ „ „
E for copper = 14,000,000.
„ „ bronze = 17,500,000.
„ „ iron = 25,000,000.

STRESSES UPON STAYS.

In order to decide the class and number of stays required, it is necessary to calculate the stresses to which

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of the effects of elasticity on telegraph wires is given in G. M. Carr's paper, "Aërial Wire Construction," before the I.P.O.E.E., February 2, 1909.

they will be subjected. As an example, assume that a terminal pole carries four 200 lb. wires, with its resultant point 24 feet from the ground, and that 7 feet is available for the spread of stay. The conditions are shown in Fig. 538, and it is required to know whether one stay is sufficient, and whether $\frac{4}{8}$ or $\frac{7}{8}$ wire should be used. The factor of safety for stays is 4.

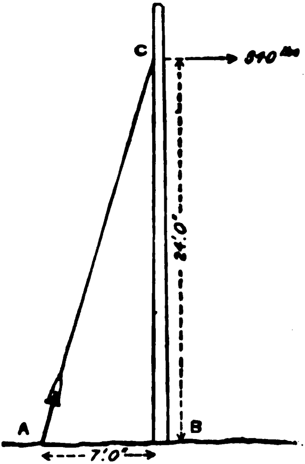

FIG. 538.—Stress upon the stay.

The horizontal stress is obtained by multiplying the number of wires by the maximum stress which results at low winter temperature; in the present case 4 × 135 lb. = 540 lb.

In order to solve this problem the following well-known theorem in mechanics is again required:—*If three forces acting at a point be in equilibrium they can be represented in magnitude and direction by the sides of any triangle which is drawn so as to have its sides respectively parallel to the directions of the forces.*[*] From this statement it will be seen that the lengths of the three sides of the triangle are proportional to the forces acting in each direction, hence:—

$$AB : AC :: 540 : \text{stress on stay.}$$

Since ABC is a right-angled triangle:—

$$AC = \sqrt{AB^2 + BC^2}$$
$$AC = \sqrt{7^2 + 24^2} = 25 \text{ feet}$$

$$\therefore \text{Stress on stay} = \frac{25}{7} \times 540 = 1930 \text{ lb. approx.}$$

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[*] Vide *Elements of Statics and Dynamics*, by S. L. Loney, or any other work on mechanics.

The breaking stress of $\frac{7}{8}$ stay wire is about 10,000 lb.

$$\left.\begin{array}{r}\text{Factor of safety}\\ \text{on a } \frac{7}{8} \text{ stay}\end{array}\right\} = \frac{10,000}{1930} = 5 \text{ approx.}$$

With a $\frac{4}{8}$ stay the factor of safety would be about 3, which is hardly sufficient.

The force tending to drive the pole into the ground is in the same ratio to the horizontal stress as the height of the resultant is to the spread. In the above case the force is therefore:—

$$\frac{24}{7} \times 540 = 1850 \text{ lb.},$$

or rather less than the stress upon the stay.

Another example of the calculation of the stress upon stays is given in order to make the principle quite clear. The pole illustrated in Fig. 539 carries thirty-two 100 lb. copper wires upon eight arms with two stays fitted as shown.

First stay.

Total horizontal stress $= 16 \times 80 = 1280$ lb.

Length of stay $= \sqrt{30^2 + 16^2} = 34$ feet

Stress on stay $= \frac{34}{16} \times 1280 = 2720$ lb.

$$\left.\begin{array}{r}\text{Factor of safety}\\ \text{on } \frac{7}{8} \text{ stay}\end{array}\right\} = \frac{10,000}{2720} = 4 \text{ approx.}$$

This may be regarded as satisfactory.

Second stay.

Since $D\,E$ is parallel to $A\,C$ the triangles of $A\,C\,B$ and $D\,E\,B$ are similar, therefore the ratio of $E\,D$ to $D\,B$ is the same as that of $C\,A$ to $A\,B$. The horizontal stress is also the same, therefore:—

$$\begin{aligned}\text{Stress on } D\,E &= \text{Stress on } A\,C\\ &= 2720 \text{ lb.}\end{aligned}$$

Factor of safety on $\frac{7}{8}$ stay $= 4$ approx.

Where the spread of a stay or stays upon a terminal pole is made equal to the height at which they are attached the combined stays should contain twice as many s as there are 400 lb. line wires carried by the pole. For terminal poles the spread should, if possible, equal the height at which the stay is attached, in which case the stress upon the stay is $\sqrt{2}$ × the horizontal stress.

At every angle in a line the pole at which the angle occurs is subjected to a horizontal stress tending to pull the pole over in a direction which would eliminate the angle. The calculation of the value of this stress is necessary to decide the kind and number of stays required.

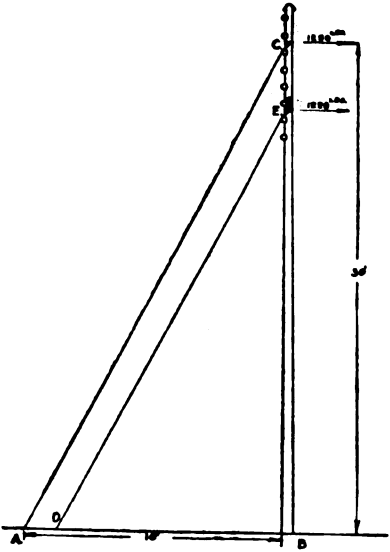

FIG. 539.—Stress upon parallel stays.

The distance which the angle pole is out of line with its immediate neighbours is readily observed or measured, and this, with the length of the span and the number and class of wires carried, provides the information necessary for calculating the horizontal stress at the resultant point.

The solution of this problem requires that the following theorem in mechanics should be known:—*If two forces,*

acting at a point, be represented in magnitude and direction by the two sides of a parallelogram drawn from one of its angular points, their resultant is represented both in magnitude and direction by the diagonal of the parallelogram passing that angular point.*

Example.—A line of 40 ft. poles carries twelve 400 lb. iron and sixteen 150 lb. copper wires. If the pole at an angle is 3 yards out of line, the length of the span upon each side being 60 yards, what stays will be required assuming that 12 feet is available for the spread of the stay? (Figs. 540 and 541.)

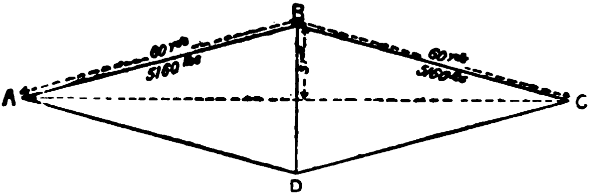

FIG. 540.—Stress upon stay due to an angle in the line.

$$\left.\begin{array}{r}\text{Total stress acting upon each}\\ \text{side of angle pole}\end{array}\right\} = \begin{array}{r} 12 \times 270 = 3240\\ 16 \times 120 = 1920\\ \hline 5160\text{ lbs.}\end{array}$$

The diagonal $B\,D = 6$ yards.

Since $A\,B\,C\,D$ represents a parallelogram of forces:—

Length of $A\,B$ or $B\,C$: Length of $B\,D$ :: stress $A\,B$ or $B\,C$: stress $B\,D$.

$$i.e.\ 60 : 6 :: 5160 : \text{Horizontal stress.}$$

$$\therefore \text{Horizontal stress} = \frac{6}{60} \times 5160 = 516 \text{ lbs.}$$

The approximate position of resultant point is upon the third arm, *i. e.* 31 feet 6 inches above the ground-line. (Assuming that the stress upon the third arm acts directly upon the stay, there is a stress of 8 × 270 lbs. balanced by a stress of 16 × 120 lb. respectively above or below the resultant point.)

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* Vide *Statics and Dynamics*, by S. L. Loney, or any work upon mechanics. The theorem may be proved experimentally or theoretically deduced from Newton's laws of motion.

$$\therefore \text{ Length of stay} = \sqrt{31{\cdot}5^2 + 12^2} = 33{\cdot}7 \text{ ft.}$$

$$\text{Stress on stay} = \frac{33{\cdot}7}{12} \times 516 = 1449 \text{ lb. approx.}$$

$$\text{Factor of safety on } \tfrac{7}{8} \text{ stay} = \frac{10{,}000}{1449} = 7 \text{ approx.}$$

If it is certain that additional wires will not, at any future time, be added to the line a $\frac{4}{8}$ stay would suffice.

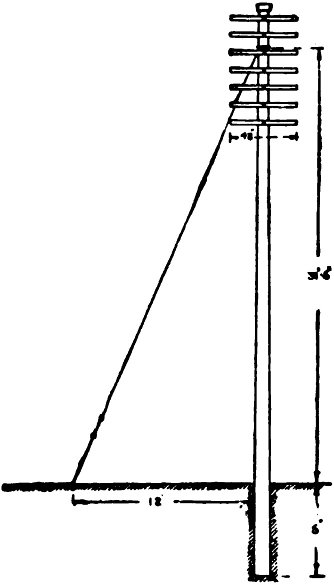

FIG. 541.—Horizontal stress on pole due to an angle in the line.

Where the two spans upon either side of the angle pole are unequal the semi-diagonal must be measured by taking a point on the longer span equal to the shorter, as indicated in Fig. 542. Here the span is 40 yards on one side and 60 upon the other. Since the stresses in the two spans are the same it will be obvious that they are represented by *A B* and *B C* and not by *A B* and *B E*.

FACTOR OF SAFETY ON AN OPEN LINE.

The stability of a line of telegraphs depends upon its ability to withstand the transverse stress exerted upon it by wind pressure. No line is considered safe unless there is a factor of safety equal to at least 8. The pressure which is exerted by the wind varies as the square of its velocity. If the pressure per square foot at a velocity of 30 miles per hour is 4·428 lb., at 60 miles per hour a pressure of 17·712 lb. will result. At 100 miles per hour the pressure is 49·2 lb., but this is a condition rarely met with. Experience has shown that for telegraph lines having a resultant about 20 feet from the ground 17 lb. per square foot may be taken as the maximum wind pressure.

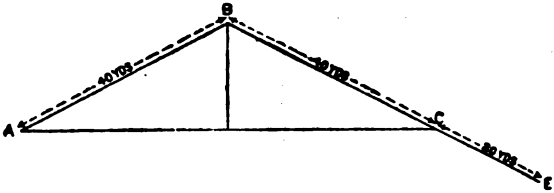

FIG. 542.—Horizontal stress on pole when the spans are of unequal length.

The stress resulting from wind pressure may be regarded as acting at the resultant point, and if, therefore, the effective exposed area is multiplied by 17 the transverse horizontal stress in lbs. will be obtained.

The horizontal stress in cwts., which must be applied at the resultant point upon a telegraph pole in order to break it, may be found from the following formula:—

$$W = \frac{4 \cdot 7 \, r^3}{l} K$$

where W = horizontal stress in cwts.;
r = radius of pole in inches;
l = height of resultant above the ground-line in inches;
K = coefficient of rupture;
11·63 for Norway round red fir;
11 for pitch-pine;
7·23 for red pine tested in whole balks.

Notes :—

(1) The wind pressure exerted upon a round wire or pole is equal to two-thirds of the pressure which would be exerted upon a flat surface of equal length with a breadth equal to the diameter of the wire or pole.

(2) The force exerted upon each pole is equal to that exerted upon the whole of the wires for a distance of half a span upon each side of the pole.

Example.—A line carrying ten 400 lb. iron wires with a resultant 20 feet above the ground-line and with 60 yard spans has poles with a diameter of 10 inches at the ground-line. Is the line safe ?

Area of wires two half spans each 30 yards.

Effective area of wires :—

$$\frac{(60 \times 36) \times (\frac{2}{3} \text{ of } \cdot 171) \times 10}{144} = 17{\cdot}1 \text{ sq. ft.}$$

Horizontal stress at resultant = 17·1 × 17 = 291 lb.

Wind pressure on the pole itself :—

Assuming that the pole tapers from 10 inches at the ground-line to 6 inches at the top, and taking the length above the ground-line as 22 feet :—

Equivalent area of pole $= 22 \times (\frac{2}{3} \text{ of } \frac{8}{12}) = 9{\cdot}7$ sq. ft.

Total wind pressure $= 9{\cdot}7 \times 17 = 166$ lb.

But this force should be regarded as acting at a point half-way (11 feet) up the pole, since its moment varies from nothing at the ground-line to its average value in the centre and to its maximum value at the top of the pole.

The horizontal stress at the resultant point 20 feet above the ground is therefore :—

$$\frac{11}{20} \times 166 = 91 \text{ lb.}$$

Total horizontal stress $= 291 + 91 = 382$ lb.

$= 3{\cdot}41$ cwt.

$$\text{Breaking stress of pole} = \frac{4{\cdot}7 \times 5^3 \times 11{\cdot}63}{20 \times 12}$$

$$= 28{\cdot}5 \text{ cwt.}$$

$$\text{Factor of safety } \frac{28{\cdot}5}{3{\cdot}4} = 8 \text{ approx.}$$

It will be useful to consider one other problem involving both static and kinetic stresses.

Example.—An angle pole 10 inches in diameter is two yards out of line with 60 yards' span upon either side. If the pole carries twenty 150 lb. copper wires with its resultant 20 feet from the ground-line, will a stay be necessary?

Horizontal stress due to angle in line $= \frac{4}{60}$ of 20×120 lb.
$= 1{\cdot}4$ cwt.

Effective area of wires $= \frac{2}{3} \times {\cdot}097 \times 20 \times 60 \times 36$ sq. in.
$= 19{\cdot}4$ sq. ft.

Wind pressure (wires) $= 19{\cdot}4 \times 17$ lb.
$= 3$ cwt.

Wind pressure (pole) $= 1$ cwt. (say).

Total horizontal stress static + kinetic $= 5{\cdot}4$ cwt.

Breaking stress of pole $= \dfrac{4{\cdot}7 \times 5^3 \times 11{\cdot}63}{20 \times 12}$
$= 28{\cdot}5$ cwt.

Factor of safety $= \dfrac{28{\cdot}5}{5{\cdot}4} = 5$ approx.

Hence a stay should be employed.

RENEWALS AND ALTERATIONS.

When it is necessary to renew the poles upon a line care must be taken to prevent interruptions to the circuits working upon the route. One method by which this work is carried out consists in using two ladders as temporary poles. The wires upon each side of the pole are unbound and attached to an insulating strip fixed to a stout ladder upon each side of the pole. These ladders are then drawn outwards and temporarily stayed to bars driven into the ground. This leaves a wide gap between the wires upon either side of the pole, which can then be lowered and the new one erected in the ordinary way.

The renewal of the wires upon a route may be effected with the aid of wiring arms (Fig. 544) fixed upon the arms of the poles. For the renewal of straight wires the arms are fixed as shown at *A* (Fig. 543) for outside, and as shown at *B* for inside wires, but, as will be seen from the sketch, they are capable of motion to any desired position between the insulators. The new wire is run through the pulleys and pulled up to approximately the correct tension. It is then transferred to the insulators and the old wire placed in, and finally drawn through, the pulleys on to a drum barrow. In this way it is possible to avoid interruptions to the circuit concerned and also to other circuits upon the poles, the wooden portion of the extension arm being relied upon to maintain a sufficient degree of insulation. There is a considerable advantage in running the new wire through pulleys instead of dragging it over the arms, and this is especially so in the case of copper wire. It may be added that a somewhat similar method is adopted in running and renewing twisted telephone wires, but in this case the arrangements are a trifle more complex.

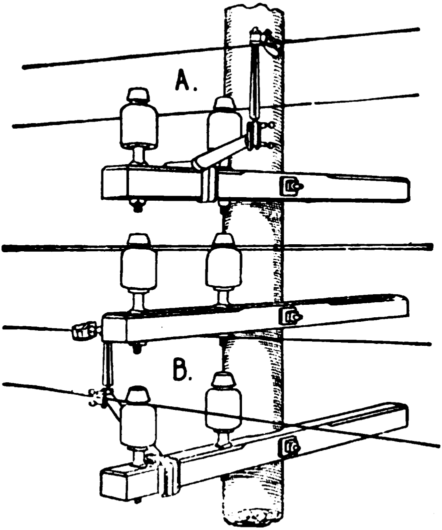

FIG. 543.—Wiring arms.

In special cases of difficult and complicated re-arrangements a special cable, termed an interruption cable, is sometimes employed. These cables are slung upon the poles, and the wires to be renewed are joined through the cable before being cut away, and the new wires are cut in before the interruption cable is cut out. If these operations are carefully performed interruptions need not occur —the guiding principle being never to cut any wire until it has been joined through the cable.

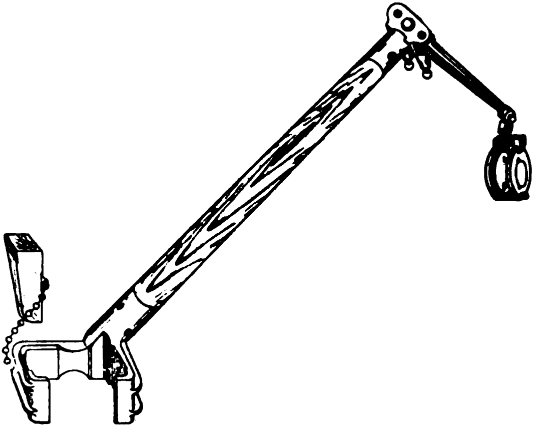

FIG. 544.—Wiring arm details.

In making a diversion of a line between any two points interruptions are avoided by erecting the new section and allowing the wires to work through both the old and the new lines in parallel. Finally the old line is cut away, but this is not done until the circuits are through upon the new section.

It goes without saying that temporary stays are frequently needed whilst the alterations are in progress. Usually they are provided by driving a crowbar into the ground and connecting it to the pole by one or more 400 lb iron wires with draw-tongs inserted to tighten the stays.

SURVEYING FOR OPEN LINES.

When it has been decided that a telegraph line shall be erected between two given points, the first work to be done is to decide upon the route to be followed—a matter upon which too much thought can scarcely be bestowed. The possible routes can at once be ascertained by consulting an ordnance map, and, other things being equal, the shortest one is chosen. Generally speaking, there are two or three alternative routes which could be used in the case of a long line, and the final decision is very frequently due solely to the facilities which the roads offer for the erection of stays and for access by the linemen. Again the probable lateral extensions of the line should receive consideration. This preliminary survey is best made by driving over the various routes, and noting any special difficulties which are likely to be encountered.

Having selected the route, a detailed survey is made in order to fix the exact positions and lengths of the poles and also to estimate the cost of the work. At the same time the method of laying out the stores and means of cartage are carefully considered. Also, a note is taken of all the wayleave consents which are required. This work should be done with the utmost care, and full notes of the decisions arrived at should be made, so that the foreman entrusted with the work can readily be given the fullest possible details of the manner in which the work is to be carried out. Frequently a considerable period elapses between the preparation of the estimate and the actual carrying out of the work, and therefore the value of accurate and full notes will be quite apparent. All the particulars enumerated can readily be entered in a Survey Book of the form shown below:—

State here the Locality, Town, Village, Bridge, or Landmark, by which the spot to which the first entry relates can generally be identified. } ______________________

____

No.	**Distance in Yards.**	**Right or left.**	**Position of Pole.**	**Description of pole.**	**Stay or Strut.**	**Arm saddle or bracket.**	**Insulator.**	**Special fittings.**	**Remarks, consents, etc.**

In fixing the positions of the poles it must be remembered that during gales the wires are blown out laterally to a distance almost equal to their dip, and therefore trees must be given as wide a berth as possible. Where the level of the road changes rapidly it is desirable to keep the height of the line fairly uniform. In any case, the heights of the poles must not vary sufficiently to produce an upward pull upon an intermediate pole. This is readily calculated by working out the dip for a span without the intermediate pole. If the pole is too short to reach the lowest point of the wire then there will be an upward pull upon the intermediate pole.

Where the wires cross over buildings chimneys should be avoided, as the effect of the heat and smoke upon the wires is of a most deleterious character. Again, poles should not be placed in positions in which well-water is likely to be contaminated by the creosote, and in all cases of suspicion where there is no possibility of avoiding it poles in which the creosote has dried should be selected, or the pole should be set in concrete.

Long slanting road crossings should be avoided—in fact, the road should be crossed as seldom as possible, but where this is essential the wires should be terminated (upon P.O. terminal insulators) at either side.

Where a long stretch of road is visible it is advisable to make the angles between the successive poles and their stays and struts as nearly uniform as possible, since this improves the general appearance of the line.

In order to limit the range of damage due to the collapse of a line, by reason of snow accumulations, or the fall of a tree across the line, double longitudinal stays are provided at intervals of about a quarter of a mile. These two stays are fixed in the line of the wires and serve to support the pole should a breakdown occur upon either side. This device is applied wherever it is possible, but unfortunately there are many cases in which the stays would seriously obstruct the road.

A single longitudinal stay is required at points where the wires change in gauge in order to balance the difference in the stresses upon either side of the pole.

In the case of small bends in the line no special provision is necessary, but where the turn is sharp, it is sometimes found that the inner wires in leaving the insulators foul the poles. Also, where the line takes a right-angled turn special fittings are employed. The pole is double armed and brackets added as indicated in Fig. 545. In such cases it is desirable to use a stay or stays in the line of each set of wires instead of a single stay bisecting the obtuse angle formed by the wires.

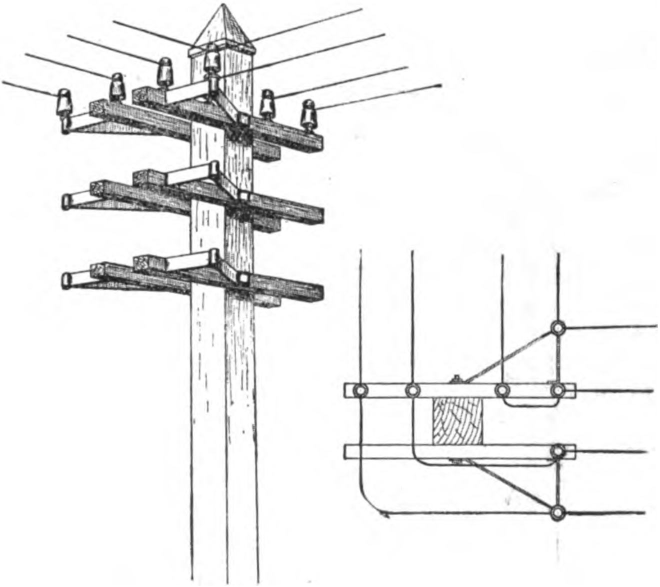

FIG. 545.—Use of terminating brackets.

A short section of line is diagrammatically shown in Fig. 546. Double longitudinal stays are shown at *A*, whilst the pole at *C* is strutted, and that at *D* is stayed across the road owing to the owner of the shaded property refusing to permit a strut to be fixed upon his land. It is, of course, also assumed that there is not space upon the road for the erection of a strut or an A-pole. A pole is erected upon the opposite side of the road and stayed by a block and rod in the ordinary way. The resultant of the first pole is stayed to the top of the stay pole, and a tightener inserted for adjustment. It goes without saying that stays erected across roads must be given sufficient elevation to provide ample headway for heavily-laden hay wagons, etc. If stays, struts, and A-poles are all impracticable the bend may be negotiated by increasing the number of poles round the bend; but this course is only followed in cases of absolute necessity.

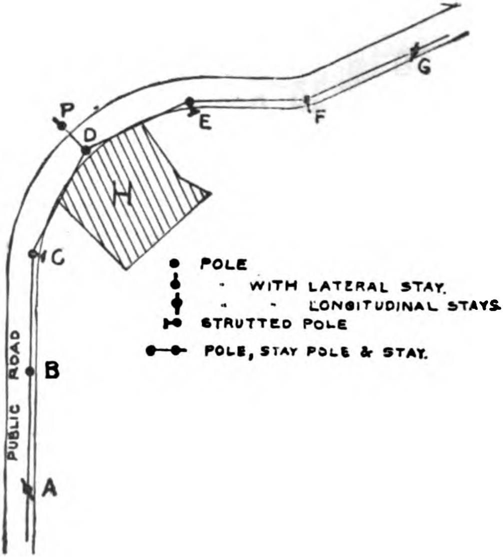

Fig. 546.—Plan of a section of line showing various stays and struts.

The poles upon each route are numbered consecutively by means of zinc number plates nailed to the poles six feet above the ground-line in order to facilitate identification for wayleave purposes and for the issuing of instructions for renewals or repairs.

In some districts heavy winds always prevail in one direction, and where this direction is at right angles to the length of the line it is advisable to add lateral stays to provide for the extra stresses which result.

Game guards, consisting of cylindrical corks, are occasionally attached to the wires along the span in order to make the wires sufficiently conspicuous for the birds to avoid them.

AERIAL CABLES.

Aerial cables are used to carry the wires beneath bridges or in other circumstances in which it is impossible to obtain clearance for open wires. In 12-, 16-, and 28-wire cables 40 lb. tinned copper conductors, having a resistance of not more than 22·699$^{\omega}$ per mile, are covered with pure Para rubber, two layers of vulcanizing India-rubber, and spirally lapped with india-rubber-covered cotton tape (capacity of core not to exceed ·378 m.f. per mile). Four cores, two coloured red and two black, are laid up round a tanned jute centre so that diagonally-opposite conductors are of dissimilar colours and are bound together by a cut cotton tape prepared with ozokerit compound. The requisite number of quadruple cores (diameter ·415 inch) are laid together, wormed with tanned jute, covered with an ozokerit-coated cotton tape laid on spirally, braided with Russian hemp-yarn prepared in ozokerit compound, and the complete cable is finally coated with the same compound. Where a larger number of wires is necessary 38-wire interruption cable is employed. The conductors are of 20 lb. tinned copper, and the thickness of the insulation is correspondingly reduced. The cores are twisted in pairs and formed into a cable with a prepared waterproof tape having a lap of ¼-inch, and then braided twice with stout cotton saturated with ozokerit.

Paper and air space insulated cables are also employed. The wires are arranged very much in an underground lead-covered cable, a lead covering being formed over the wires. The ends are terminated by pothead joints, *i. e.* joints within a sleeve made solid by filling up the spaces with insulating compound (see Chapter XXIII).

Every three feet a raw hide suspender with a double hook of the form illustrated in Fig. 547 is attached to the cable. The suspending wire consists of one or more 400 lb. bimetallic wires (steel core with an electrolytic deposit of copper) having a breaking weight of 2160 lb., terminated at each pole, and, in order to avoid longitudinal stresses upon the cable, the cable is securely lashed to each pole with ozokerit tape.

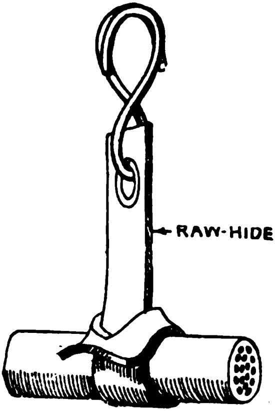

FIG. 547.—Raw hide suspender for aerial cables.

The suspending wire is first erected, and the raw hide suspenders attached to the cable. The hooks are passed over the wire and the cable drawn along by a rope. In this way the weight of the cable is borne by the suspending wire even whilst being erected.

The cable should be fixed as low down the pole as practicable, and chimneys must be carefully avoided owing to the action of the smoke. All risk of chafing must also be obviated. A reasonable factor of safety upon the suspending wires must be secured, and in cases where the dip has to be greatly restricted additional suspending wires may be necessary. It is, however, a simple matter to calculate the stresses with the aid of a formulæ on page 825 and a knowledge of the weight of the cable. The pole at which the open wires pass into the aerial cable usually requires a longitudinal stay to pull against the open wires.

The use of aerial cables is confined to cases of absolute necessity on account of their cost and the resistance and capacity of the wires. Moreover, the life of the cable is limited, and mere inspection fails to reveal incipient defects.

OVERHOUSE CONSTRUCTION.

The term "overhouse" is employed to denote all those cases in which the wires are carried upon supports fixed to buildings, or in which timber of exceptional length is necessary, but the object of the present section is to deal only with the former cases.

The line wire is invariably either copper or bronze of a light character in order to reduce the stress to the lowest possible limit. If solid wires are used, 70 lb. bronze, 100 lb. copper or even 150 lb. copper may be chosen, but when trouble arises from the humming of the wires, either $\frac{3}{18}$ or, where it is imperative to keep down the resistance of the circuit, $\frac{7}{18}$ stranded copper (see table on page 786) wire is employed. The wires are terminated at very frequent intervals, thus securing greater immunity from breakages, and illiminating the possibility of a broken wire running back through an imperfectly attached binder. Upon each side of every street crossed by the route the wires are invariably terminated and the length of the span is kept as short as possible. When wiring operations are in progress men are stationed in positions where they can readily stop the traffic in the event of a wire being in such a position as to cause danger, but in most cases the wires are pulled across with the aid of an endless sashline, thus obviating interference with the traffic below. The only other point calling for particular mention is the danger attaching to the use of a fire-pot upon a roof: it should be placed upon stone or brickwork, kept well clear of any lead work, and a man should always be left in charge of it.

HUMMING OF WIRES. SILENCING DEVICES.

The well-known humming noise which is produced by telegraph wires under certain atmospheric conditions is usually of little or no consequence in the case of road lines, but when the wires are carried by supports fixed to buildings, the sound is transmitted by the walls and partitions to the interior. In some cases, no doubt, resonance also tends to increase the noise to such an extent as to cause most serious annoyance. The effect is greatest when the wires are erected in long spans and are tightly stretched, but it is noticeable that the volume of the noise is not in direct proportion to the velocity of the wind, since it is frequently greatest upon a comparatively calm day. Many silencing devices (variously termed *sourdines*, deafeners, and silencers) of a more or less effective character have been devised.

When the wires terminate upon a support fixed to a building, as for example upon a bracket, the noise can be very greatly reduced by terminating and slackening out the wires in the last span. In addition the line wire may be covered with india-rubber by placing a length of tubing over the wire where it passes around the insulator; or again a strip of wood about two feet long bound round each wire close to the insulator will sometimes prove quite effectual.

In the case of roof standards (see Fig. 552) it will be observed that there is a packing of lead and felt between the chair and the ridge of the roof which tends to insulate the vibrations.

Sourdine Caël Beau. Yarn to a thickness equal to the diameter of the wire is tightly wrapped round the line wire for a distance of about twelve inches. Over this is placed a split rubber tube of such a diameter as completely to enclose the yarn, and finally a wrapping of lead is placed over the rubber tube. The binding wire where it encircles the insulator is treated in a precisely similar manner and the ends are made off upon the leaden covering of the line wire.

The late N.T. Co.'s standard arrangement. A narrow strip of thin lead is wrapped around the wire for a distance of eight inches upon each side of the insulator, the central portion taking one turn around the insulator. Its efficiency may, however, be increased by placing yarn between the wire and leaden wrapping.

Chain silencer. A short length of chain is inserted in the line wire and the ends bridged across by a length of conductor so as to preserve the electrical continuity of the circuit.

For brackets. A rubber washer placed between the flange of the insulator spindle and the top of the bracket, and one between the nut and the bottom of the bracket, is most effective and greatly diminishes the noise.

In conclusion of this subject, it should be stated that light stranded copper wire produces far less noise than a solid wire under similar conditions.

BRACKETS.

Angle brackets, fixed upon the corners of walls and chimneys, are frequently employed when the route is to carry a maximum of six wires. The brackets should only be attached to sound buildings, and a wall is to be preferred to a chimney, but where the latter is the only available position the brackets should be kept as low as possible. It is also very desirable to arrange matters so that the stress upon the bracket, due to an angle in the line, tends to push the bracket on to, and not pull it away from, the chimney. In the former case the only function of the nails is to support the bracket, whilst in the latter they have to resist a definite stress, and the brickwork will therefore require to be plugged—frequently a hazardous proceeding, since most chimneys are only 4½-inch brickwork.

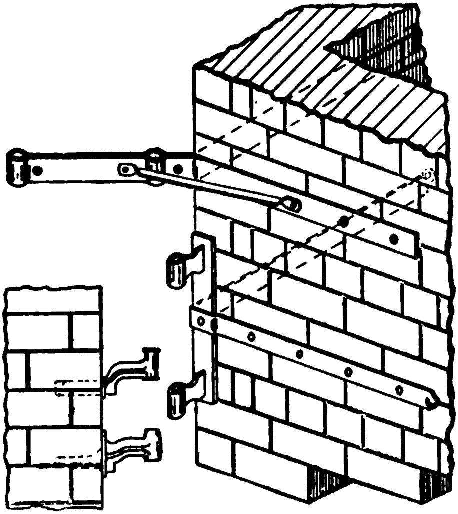

FIG. 548.—Double horizontal and vertical brackets and single bracket.

The double vertical bracket (Fig. 548) is suitable for use upon chimney stacks owing to the provision of the two eyes, by means of which a $\frac{7}{14}$ stranded iron stay wire may be passed around the stack. At each of the three corners an angle plate 9 inches deep carrying a projecting eye is fixed, so as to prevent the stay wire from cutting into the brickwork (see also Fig. 549). This arrangement obviates the necessity for using so many nails, and so saves the chimney from any unnecessary damage and the occupants of the house from a certain amount of annoyance, due to falling soot and noise, which occurs whilst the bracket is being fixed.

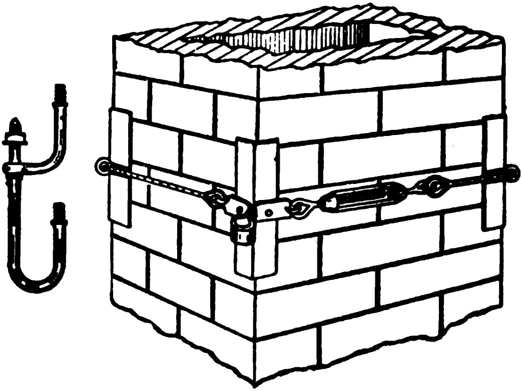

FIG. 549.—Chimney bracket and fixings.

The double vertical bracket has been superseded by the arrangement shown in Fig. 549 in which the insulator spindle is arranged to take two insulators.

The horizontal bracket (Fig. 548) is used only upon the corners of buildings of substantial character owing to the fact that the leverage of the outer wire is very considerable.

STANDARDS.

The safety of a building would be imperilled if its roof timbers were utilized for the same purpose as the five or six feet of earth in which a ground pole is embedded, viz. to hold the base of the pole rigid when the upper portions are subjected to lateral stresses due to wind pressure. In the event of the collapse of the wires upon one side of the standard, such as might for example be caused by a fire at an adjacent building, a very heavy strain in a direction at right angles to that produced by wind pressure across the wires would result. It is therefore necessary so to arrange the structure that the only stress upon the roof shall be in a downward direction, and this is readily accomplished by the employment of four or more stays. Motion of the pole is resisted by tensile stresses upon the stays and by downward or crushing stress upon the pole. Every roof pole is stayed in four directions, and it is preferable to arrange the stays so that the line of the wires bisects the opposite angles formed by the plan of the four stays. In this way either a laterally or a longitudinally applied stress is divided between two stays (see Fig. 552).

The average roof is not constructed with a view to the erection of a standard upon it, and the conditions to be met in each case vary so much that it is only possible to describe two or three typical cases, and from them illustrate the general underlying features of satisfactory design. The stresses should be transmitted to the outer or main walls in such a manner that the standard becomes an integral part of the building to which it is attached. It should be ascertained that the roof timber is of such dimensions as to take safely the extra stress thrown upon it, should the whole of the wires collapse upon either side of the pole; and where this is not the case an additional beam of timber or a suitable steel joist connecting the main walls should be added. The stays should be anchored low enough down the main wall: the stress, if considerable, being distributed by using wall plates, to ensure that the brickwork shall not be displaced by any stresses to which the stays can conceivably be subjected. The *lateral* stresses upon the walls must be reduced to the lowest possible limits, whilst an upward pull upon the rafters of the roof is especially to be avoided. It is particularly inadvisable to bolt a pole to an end wall when thoroughly efficient staying facilities are not available.

Buildings which have been specially constructed for the reception of large standards are so arranged that, in some cases, the poles pass right down to the foundations and are braced together and stayed to the walls in such a manner that nothing short of a collapse of the whole building could affect their security.

Square pitch pine poles passing through the roof of the building were at one time somewhat extensively employed, but since the pole is subject to vibration there is some difficulty in maintaining a perfectly watertight joint at the point where the pole passes through the roof.

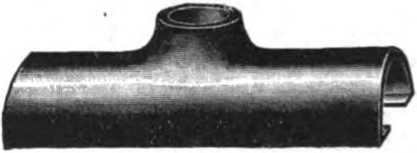

FIG. 550.—Chair for roof-poles.

The present practice is to use iron poles carried by a cast-iron chair (Fig. 550) placed upon the ridge of the roof as shown in Fig. 552. The pole itself is dipped whilst hot into boiled linseed oil, since it is found that this treatment is more effective than galvanizing. Felt and lead are placed beneath the chair in order to prevent the vibrations due to the humming of the wires, from being transmitted through the roof timbers to the interior of the building. Climbing clips, which correspond to the pole steps used upon ground poles, are fitted at regular intervals and at the upper part of the tube a collar for the attachment of the stays is shrunk on. The tubular iron arms are of the same pattern as those used with iron ground poles (see Fig. 529) and are furnished with wooden insulating strips as previously described.

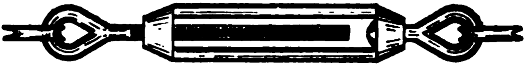

FIG. 551.—Swivel for stays upon overhouse fixtures.

The stays should, where possible, be anchored to the main walls of the building sufficiently low down for security.

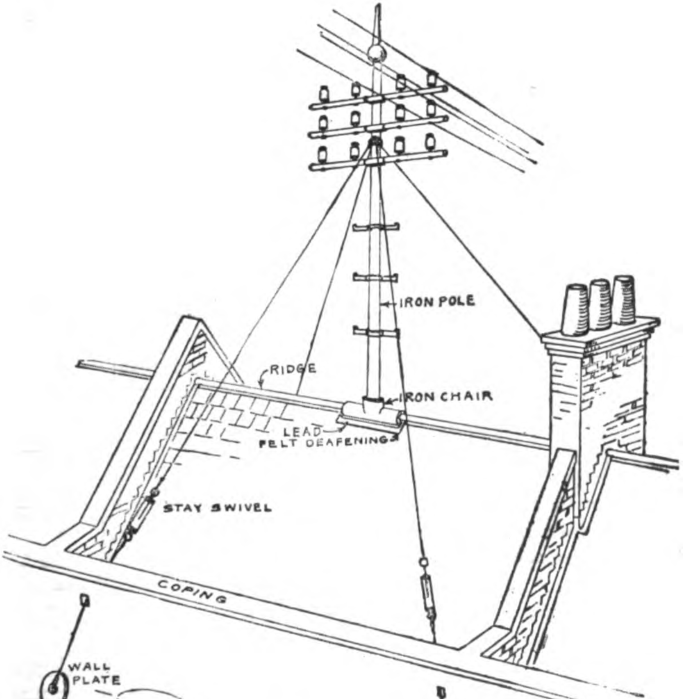

FIG. 552.—Single roof-pole standard showing three methods of anchoring the stays.

Where the beams of the roof are employed, collars should be fitted, and under no circumstances should bolt holes be cut. Care must also be taken not to put a stress upon

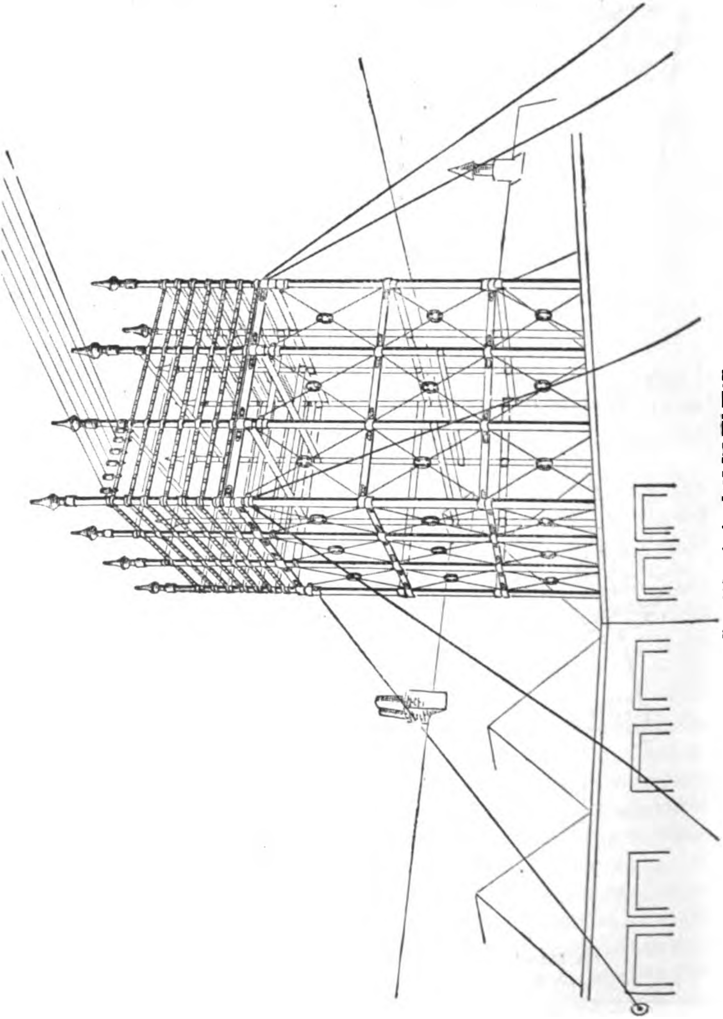

FIG. 558.—A standard for 304 wires.

coping which tends to displace it. In the majority of cases a hole is provided for the stay, as shown in Fig. 552, but by fixing a block of wood of triangular section with its base uppermost at the bottom of the coping wall, it is sometimes possible to obtain a satisfactory clearance.

Three methods of anchoring the stays, each of which is fitted with a swivel (Fig. 551), are shown in Fig. 552 firstly by means of an eye spike driven into the brickwork, secondly by means of a G.I. strap nailed to the wall, and thirdly with the aid of wall plates. The last method consists in placing a plate upon each side of the wall and bolting them together, thus ensuring a thoroughly efficient hold upon the brickwork. In the case of very heavy stresses the size of the plates may be increased, and the two sides bolted together independently of the eye bolt to which the stay is attached, the effect being to thus distribute the stress over a large area. The use of wall straps, owing to their inefficiency, is avoided, wherever it is possible.

Where the standard is to be fixed upon a girder or upon the end of a wall, a chair of rectangular section to fit over the wall or girder is substituted for the semi-circular chair shown in Fig. 552.

A double or two-pole standard is carried by a rolled steel joist upon which the two cast-iron chairs are placed and the poles are braced together in a manner very similar to that employed for H-poles, whilst the channel iron arms serve to secure the upper portions of the poles. These arms are made in two pieces and are bolted together upon each side of each insulator spindle and each pole hole.

In the case of P.O. buildings, walls are extended upwards and are spanned by the girders carrying the standard. These are held down by long anchor rods terminating on anchor plates fixed to the walls.*

An example of a large standard designed by M. F. Roberts is illustrated in Fig. 553. In the centre of the large well of the building a heavy brick tower was built and the standard placed upon it. It will be observed that the general construction bears some resemblance to the H-poles previously described and that the various poles are also braced across in such a manner as to secure remarkable strength and rigidity. The channel iron arms serve to brace the heads of the poles and the structure is capable of carrying 504 wires.

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* A number of examples are given in J. H. M. Wakefield's paper, "The Construction of Aerial Lines," read before the I.P.O.E.E., December 9, 1907.

Here it may be well to point out that standards are extremely costly structures and that therefore very considerable economy will result, if a single or an H-pole can be made to serve the purpose. For most small offices which are not unduly high, or where space is available at the sides or back, an office pole is greatly to be preferred to a standard.

CHAPTER XXIII

THE CONSTRUCTION OF UNDERGROUND LINES.

IN the centre and in the more congested parts of large towns and cities, as also in cases where the number of wires required exceeds the capacity of an aerial line, there is no alternative to the provision of underground routes. It has been shown that the high capacity of covered circuits gives a much lower speed of working than corresponding aerial wires. Further, the cost of an underground greatly exceeds that of an aerial, route, but where several aerial routes would be required in place of a single underground route the latter becomes the cheaper method to adopt.

The greatest advantage derived from the use of underground, as opposed to aerial, lines lies in the greater immunity from interruptions. An aerial line may be broken down by the force of a gale, the wires may be broken by the weight of snow and ice which they have to bear, insulators may be fractured by stone-throwing, or the insulation may be impaired by wet weather. From each of these sources of trouble the underground line is free, whilst the only likely causes of trouble lie in (1) the damage which may be done during road repair, (2) contacts with electric light feeders, and (3) a general sinking of the ground in which the pipes or ducts are laid. The number of cases in which any of these difficulties appear is well-nigh insignificant.

Underground wires are less accessible than open ones, and the difficulty in dealing with faults is enormously increased, but the number of such faults is extremely small.

The provision of main routes of underground connecting the larger towns and cities ensures that the telegraph work of the country shall not be disorganized by the prevalence of storms.

CONDUITS.

Many forms of conduit have been proposed, but iron pipes and earthenware ducts are the only forms used by the Post Office. One administration went so far as to dispense with the conduit altogether and to lay their telephone cable directly in the earth. The cable is, of course, protected by suitable armouring, and upon the score of economy in first cost there is perhaps something to be said for such a system. Its disadvantage is that the changing or renewal of a cable entails opening the streets—a very costly proceeding.

IRON PIPES.

The pipes are cast from soft pig-iron of good quality, and, after being thoroughly cleaned to remove all sand, grit, or metallic excrescences, are heated, and then dipped into Dr. Angus Smith's composition.*

This composition produces a hard glaze upon the surfaces of the pipes, which tends to protect them against rusting.

The specification for each size of pipe states the minimum internal diameter and also the minimum weight of the pipe, which fixes the thickness of the metal. The pipes are tested with a circular gauging disc having a diameter one-sixteenth of an inch less than the internal diameter of the pipes. The other important points to be observed are that the pipes shall be straight, smooth, and the thickness of the metal quite uniform.

The four sizes of the pipe used by the Post Office are distinguished by quoting the internal diameters. The 2″ pipes are made in lengths which give a "lay" of 6 feet, whilst the 3″, 3½″ and 4″ pipes have a lay of 9 feet per pipe—for example, 150 2″ pipes or 100 3″ pipes are required to provide 300 yards of conduit.

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* Coal tar, 1 cwt. ; tallow, 7 lbs. ; quicklime, slaked, 10 lbs. ; pine resin, 4 lbs. ; coal naphtha, sufficient to thin the composition to a degree suitable for proper coating.

A 3″ pipe is illustrated in Fig. 554, from which it will be observed that the spigot end is rounded off so as to fit into the socket of the subsequent pipe. In order to joint the pipes the spigot end is placed within the following pipe, after which a suitable quantity (about two inches deep) of spun yarn is lightly wrapped round the pipe, and driven home with a caulking iron. In order to fill the annular space between the spigot and socket ends or the pipes with lead, a roll of plastic clay is laid around the edge of the socket so as to leave an opening at the top. Through this, molten lead is poured, and after cooling for about one minute, the clay is removed. The lead is well punned with the aid of a lead set of suitable dimensions, so producing an air and water tight joint of considerable strength (Fig. 555). If the yarn is omitted, the molten lead runs into the pipe, which it effectually blocks, but this should be discovered when testing the pipes during laying.

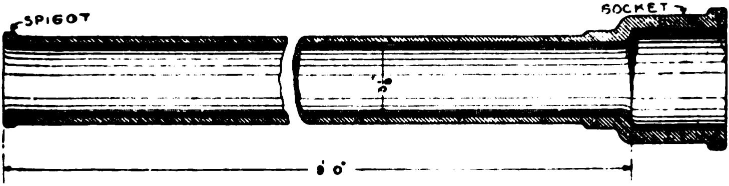

FIG. 554.—A 3″ cast-iron pipe.

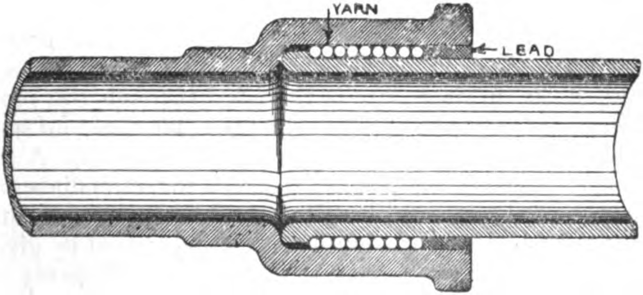

FIG. 555.—Joint between two lengths of pipe

Usually the pipes are jointed in pairs at the side of the trench, and, for this purpose, they are laid upon wooden pipe blocks which raise them about six inches from the ground. When more than two pipes are so jointed there is some risk of the joints being opened by the stresses put upon them whilst carrying to the trench. As each length is laid, the mouth of the pipe is closed by a wooden plug in order to prevent the ingress of stones and dirt from the trench.

The pipes are laid directly in the ground without any concrete or other foundation, since the nature of their design gives them very great strength.

When two or more pipes are laid in a single trench the pipe joints should be so spaced that they do not occur at the same points along the route, since this is economical in the space occupied, and also tends towards greater rigidity. As each length is laid a "draw wire" consisting of 200-lb. iron wire is threaded through the pipes. This wire serves to pull through the cable rope and saves the labour involved in using sweeps' rods (*q.v.*). A wire is not drawn into pipes not required for immediate use, as the wire may rust, break up, and cause trouble later.

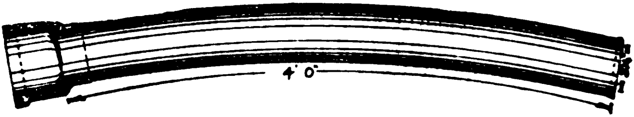

FIG. 556.—A 4' solid $\frac{1}{16}$ bend for 3" pipes.

Slight curves in the route may be negotiated by giving the pipes a slight set at the joints, but whenever the curve is of a pronounced character curved pipes or bends (Fig. 556) are used. A number of bends of varying lengths and curvature, some provided with sockets at both ends and some with spigot and socket ends, have been designed to meet these cases. The $\frac{1}{16}$ bends with a lay of 6 feet are probably used more often than any of the others, although the $\frac{1}{8}$ and $\frac{1}{32}$ bends are also extensively employed. The terms $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, $\frac{1}{32}$ denote the fraction of the total circumference of the circle which the bends represent. For instance, the $\frac{1}{16}$ 6-feet bend has the curvature of $\frac{1}{16}$ of a circle 14 feet in radius.

The cost of constructing a line of conduits varies very considerably with the character of the roadway or footway which is disturbed. The cost per yard run of a 3-inch pipe laid beneath a gravel footway might be as low as 3*s.* 6*d.*, whilst beneath a wood block carriage-way it might be in excess of 21*s.* The difference is almost entirely due to the cost of reinstating the footway between the edges of the trench line.

The following figures * show the average prices charged by the various Metropolitan local authorities for the reinstatement of trenches—

† York stone	1*s.* 8·64*d.*	per sq. yd.
Tar paving	4*s.* 0·76*d.*	„
Asphalt footway	8*s.* 6·31*d.*	„
Asphalt carriage-way	14*s.* 3*d.*	„
Pitched „ relaid on concrete	4*s.* 10·66*d.*	„
Macadam	2*s.* 2·3*d.*	„
Ballast or flints	1*s.* 6·35*d.*	„
Wood relaid	15*s.* 11·4*d.*	„
† Brick	3*s.* 5·75*d.*	„

Beneath footways the pipes are laid at a minimum depth of 14 inches, but under roadways a minimum depth of 2 feet is essential.

STEEL PIPES.

Steel pipes are lighter than cast-iron pipes, and although they cost more than the latter they have properties which render them very useful in meeting contingencies and obstacles. They are made of mild steel and can be bent locally, and as the sockets are small they are particularly useful for bridge crossing, either built into the bridge or supported on the outside of the bridge.

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* Extracted from a return prepared by the Lambeth (London) Council. *Electrician*, 5th August, 1904, page 653.

† In these two cases must be added the cost of replacing all broken or damaged stones or bricks.

Steel pipes are supplied in lengths varying from 14 feet to 30 feet.

The type of steel pipe used by the Department is illustrated in Fig. 557.

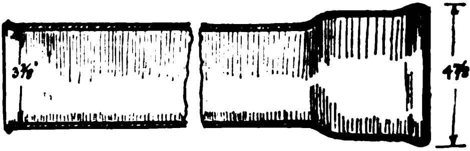


Fig. 557.—Steel pipe.

The connection between the steel pipes and multiple-way duct is made with the aid of a special double-socket duct, one end of which is dimensioned to receive the steel pipes, and the other to join up the ducts.

Duct Routes.

Where a large number of conduits is needed along a congested route, such as is met with in London and ther large cities, it is more economical to use earthenware ducts in place of iron pipes, and the larger the number required the greater is the saving effected. The duct used by the Post Office is 18 inches long with a 3¼-inch or 3½-inch circular bore and an octagonal exterior (Fig. 558). The ducts are laid upon a strengthened concrete foundation and are jointed with ozokerit tape

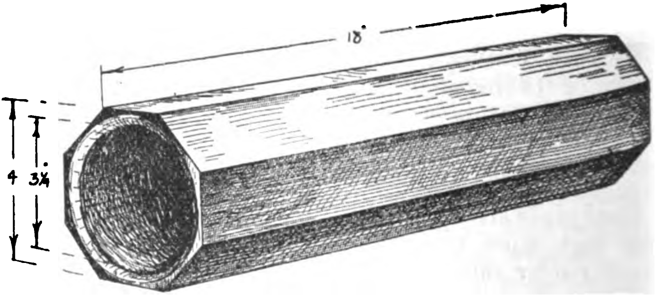


Fig. 558.—An earthenware duct

(4 inches wide) laid around the joint. Two inches of the tape upon each side of the joint adhere to the successive ducts, but it is really to the rigidity of the foundation that the joint owes its perfection.

A train of mandrels is placed in each duct line and is pulled forward as each joint is made (Fig. 559). This ensures perfect alignment by preventing any length of duct from sinking or falling after being laid. When the manhole is reached a mandrel 5 feet long is employed to preclude the possibility of disturbance to the nearer joints whilst the chamber is being constructed. Finally, the ducts are tested by drawing a mandrel through the whole section and are cleaned out by the circular brush which follows it.

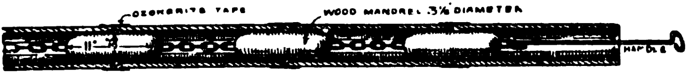


FIG. 559.—Train of mandrels in the ducts during the process of laying.

A trench of suitable dimensions is formed and a 3-inch layer of concrete laid down (Fig. 560). Upon this, one, two, or more T-irons, jointed up by fishplates, are placed and covered by a second 3-inch layer of concrete. This foundation is allowed to set for 24 hours, after which a thin layer of cement mortar or "compo" is formed, and the first or lowest row of ducts bedded upon it. More "compo" is added and the subsequent tier of ducts laid down, and so on, until the complete nest of conduits has been built up. The sides and top are lined by a solid concrete wall of from four to seven inches in thickness according to the type of paving and the number of ducts to be laid.

Consideration will show that this form of construction results in a compact block of conduits (Fig. 561) of considerable rigidity, the T-iron serving to prevent any possibility of vertical displacement. The joints between the successive ducts are not made at the same points along the route, but are "broken" as indicated in Fig. 560, a 24-inch duct being employed.

It will be realized that ducts do not lend themselves to the negotiation of curves, and in such cases iron pipes are used in the curvilinear section, the joint between iron pipes and a nest of ducts being made by means of an iron pipe with one octagonal end. The single duct used by the Post Office possesses the advantage that the arrangement of the group may be varied to clear obstacles *en route*, whereas a multiple-way duct cannot, and it is, no doubt, largely due to this fact that the single duct was originally adopted.

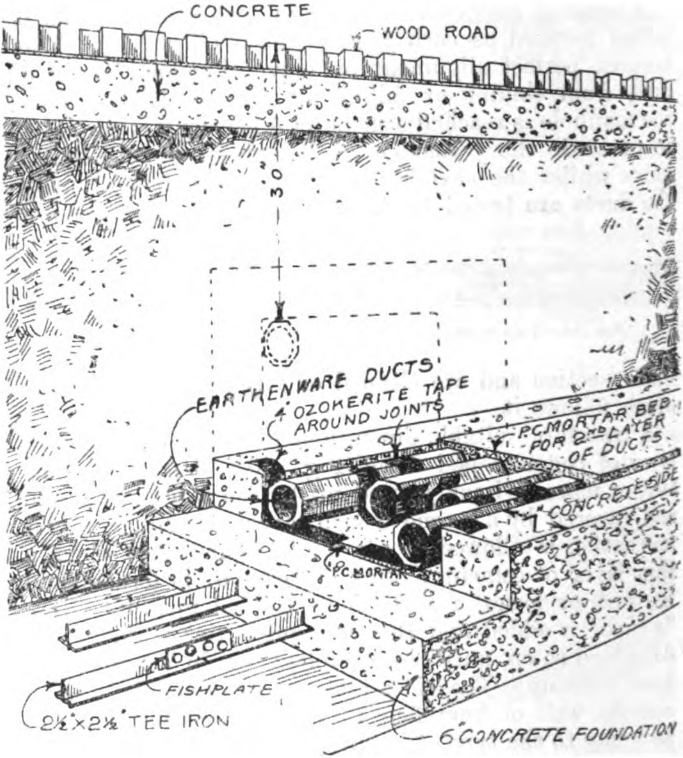


FIG. 560.—Formation and method of constructing a duct route.

SINGLE AND MULTPLE WAY EARTHENWARE CONDUITS.

Earthenware ducts are cheaper than cast-iron pipes, therefore the use of this type of conduit has been extended and, whenever the circumstances permit, earthenware ducts are laid in preference to cast-iron pipes.

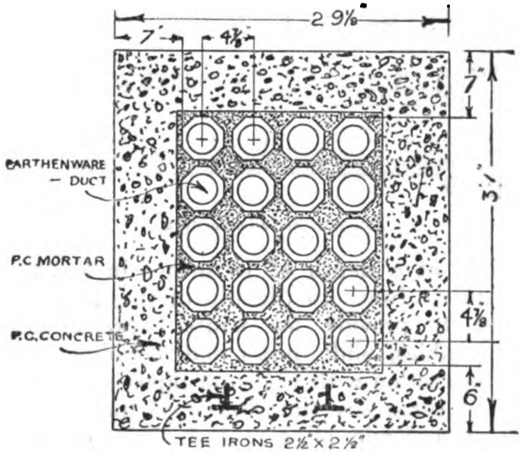
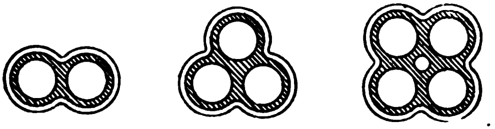
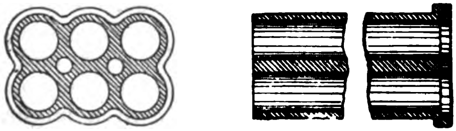


Fig. 561.—Section of a duct route.



Two way. Three way. Four way.



Six way. Section.

Fig. 562.—Various types of multiple-way duct.

The various types of earthenware ducts are shown in Fig. 562.

The single-way duct (Fig. 563) is made in two sizes, one having a 3-inch and the other a 4-inch internal diameter.

The two-way, three-way, four-way, six-way and nine-way (multiple-way) ducts are 3½ inches in diameter and 2′ 0″ and 2′ 6″ in length, the bends being 1′ 6″ in length, and are laid at a depth of 18 inches in footways and 24 inches in roadways to the top of the ducts.

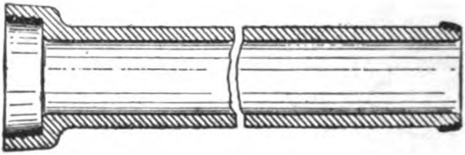


FIG. 563.—Self-aligning duct.

In order to provide for joints between successive lengths of cables, slide pipes and couplings are provided in connection with cast-iron pipes, single-way, and two-way and three-way (multiple-way) ducts.

Use is also made of a cheap form of troughing made of stoneware, known as "U" troughing. It is used for telephone purposes in sparsely populated areas, and where it is anticipated that the number of wires required will not exceed one hundred. The troughing is laid at a depth of 4 inches under stone, asphalt, and such pavings, 6 inches under tarred footways, and 12 inches under costly pavings where it may ultimately be necessary to draw out the cable and draw in a larger. Under carriage-ways a depth of 24 inches is given.

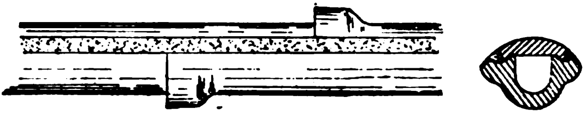


FIG. 564.—U troughing.

CAST-IRON SLIDE PIPES.

Two methods of providing for the joints between successive lengths of air-space cable have been used.

The first consists in leaving a suitable gap in the cast-iron pipe line at each point where a joint is required, and to cover the completed joint by means of a slide pipe. Before the joint between the two lengths of cable is made a pipe 4 feet 8 inches long and 4 inches in internal diameter is slipped over one end of the 3-inch pipe and pushed back out of the way of the cable. The cable joint is then made and tested and the slide pipe pulled over so that its ends overlap the ends of the pipes upon either side. Yarn is then worked in between the ends of the slide pipe and the ends of the pipe line and the joint leaded in the ordinary way, thus securing an air and water-tight joint.

Whenever it is necessary to obtain access to the joints, the ground is opened and the lead picked out from the joints with the aid of a special sharp-pointed tool. When it is necessary for any purpose to cut the pipes, the gap thus made is filled by using a length of split pipe, *i.e.* a pipe made in two halves which are secured together by four pairs of cotters and pins.

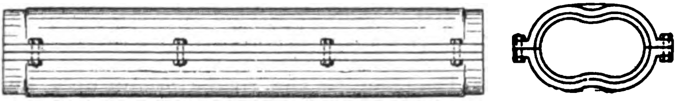


FIG. 565.—Cast-iron coupling for two-way earthenware duct.

In addition to slide pipes there is quite a number of couplings used, some to enclose an ordinary cable joint or joints, while others have, in addition, special branches to which lateral pipe routes can be connected and which provide for distribution cables being led off a main cable. Some typical couplings are shown in Figs. 565, 566 and 567.

Two branches are provided on the branch flanged coupling, and where one or both of these are not required at the time the route is laid, plugs are inserted in order to prevent earth entering.

The positions at which joints have been made are, of course, carefully recorded, but, in addition, cast-iron "markers" are placed above the joints flush with the paving, or, where no paving exists, a marking post (Fig. 568) stating the horizontal distance from the sign to the joint is placed at the side of the road. As it may be many years before it is necessary to disturb the ground there is less disadvantage in this procedure than would, at first sight, be imagined. The first cost of the system is, of course, far less than that in which jointing chambers are employed.

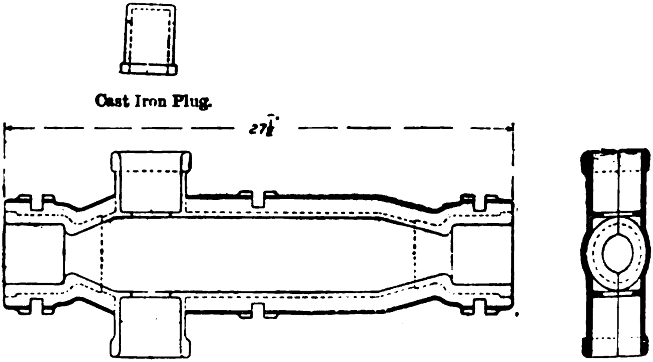


FIG. 566.—Flanged branch coupling for lateral pipes on a 2″ cast-iron pipe.

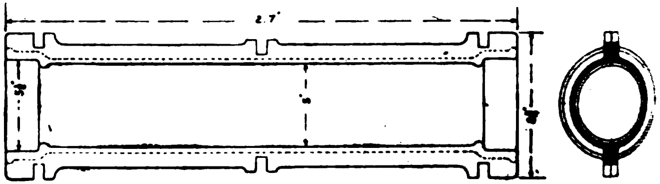


FIG. 567.—Cast-iron coupling for use with 4″ earthenware ducts.

In those cases in which the lead cable joint is provided with an air nozzle the slide pipe cannot be used, and a flanged coupling, consisting of a longitudinally split pipe provided with flanges for securing the two sections together, and having the upper half shaped to provide a longitudinal groove, is employed.

The present practice is to confine the use of slide pipes or couplings to those cases in which but one or two pipes, or 2-way or 3-way ducts have to be laid beneath the roadway, as, for example, in the case of a country road in which there is no defined footway upon either side, the construction of roadway manholes being exceedingly costly, whilst the ordinary forms of joint box and their covers are not designed to withstand the stresses produced by heavy wheeled traffic.

It should be stated that the use of slide pipes or couplings entails the making of a hole of fairly large dimensions for the pulling in and subsequent jointing of the cables.

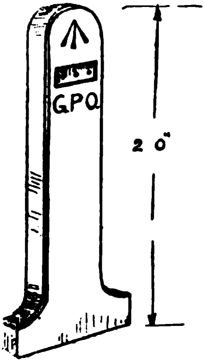


FIG. 568.—Marking post.

PILLAR TEST BOXES.

The slide pipe system is used in the case of long main routes, and at long intervals pillar test boxes are inserted to provide testing facilities where necessary. These boxes somewhat resemble the section boxes used for electric tramway routes and rest upon 12 inches of brickwork built upon about 6 inches of concrete. About 10 inches of the cast-iron frame of the pillar, which is five feet in height, is below the ground line. The upper portion of the box contains space and fittings for the reception of a cable connection box (*q. v.*) of suitable form.

FLUSH BOXES AND PIT CHANNELS.

In towns and on routes where access to the cables is required for distribution or other purposes the varying requirements are met by using six standard sizes of joint box having the dimensions shown in the table on next page.

The distribution box is used at the point to which the house connections are brought on underground distribution telephone systems; joints in the 7-pair cables are never made in them. The type of box chosen depends entirely upon the number of pipes, the angles at which they enter and leave the box, and upon the space required by the joint or joints.

Type.	Length.	Breadth.
Distribution . .	1′ 3″	9″
Small . . .	2′ 5″	10″
Large . . .	3′	15″
Extra Large . .	3′	18″
Single Junction .	2′	2′
Double Junction .	4′ 4″	2′

The special purpose of the single-junction box is to provide for a lateral pipe at the corner of a street. It is also used where there are right-angle turns in the route. The double-junction box provides for large numbers of wires or large cable joints, and is used where the main route consists of two pipes.

The extra large type is adequate for two pipes provided that there is sufficient room for jointing the cables, and, as will have been noticed, it is of the same length as, but of greater width than, the "large" box.

In order to reduce the size of the boxes needed for making joints in large cables "terminating pipes" are frequently employed. A "3 to 4 inch terminating pipe" consists of a pipe 4 inches in diameter, but narrowed down at the point where it is jointed to the socket of the ordinary 3″ pipe. In this way the lead jointing sleeve may be pushed up the terminating pipe and thus reduce the length of the jointing chamber to that actually occupied by the joint itself, but allowing, in addition, suitable room for working.

The construction of the various types of box differs in little save their dimensions, and a detailed description of a "large" box will probably suffice to render the general arrangements of the various types quite apparent.

The cast-iron body of a large box, together with its more important dimensions, are shown in Fig. 569. The lid (Fig. 570) consists of an iron casting, so shaped as to receive and support the slab of York or artificial stone (3″ in thickness) which is cemented to it. Since the lip of the cover projects over the edges of the box body, it is frequently necessary to protect the lip by placing an edging of stone 2″ wide and 4½″ deep right round the box (see Fig. 571). Where the paving is of York or artificial stone the edging may, of course, be omitted.

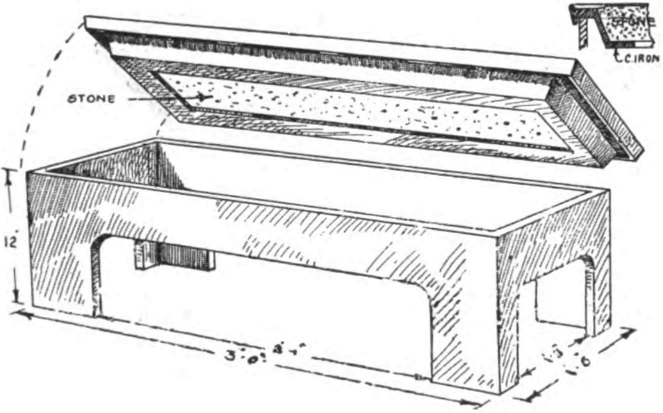


Fig. 569.—An extra large joint box.

When the line of pipes is being laid the requisite gaps are left at each box, but care is taken that the ends of the pipes shall terminate at the spigot ends, which is readily effected by cutting the last pipe to the requisite length and making the joint with the *cut* end.

A hole of suitable dimensions is prepared and the bottom lined with 3″ of concrete upon which one, two, or more courses of bricks are built according to the requirements of the case. Upon the top of this the box body is placed and bricked up in the manner indicated in Fig. 571, the pipe entering the box within the hollowed end of the body. Where the pipe enters at a lower level it is customary to increase the depth of the box so that there are two courses of brickwork below the lower pipe.

The double-junction box is provided with two lids, each 2 feet square, of the same type as that used on single-junction boxes. The centre of the box, where the two lids meet, is provided with a removable crosspiece upon which the lids normally rest. Apart from this there is nothing which calls for comment in the five types of box not discussed in detail.

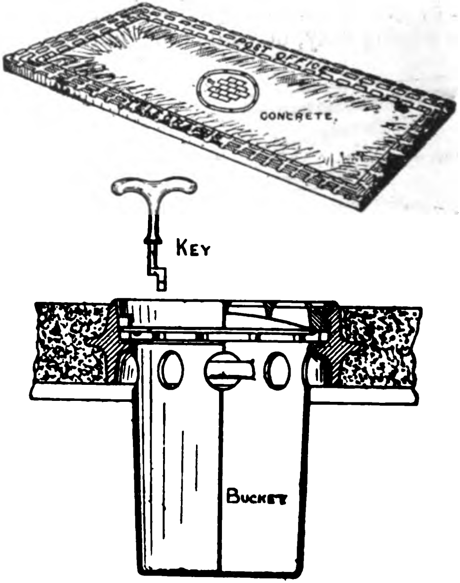


Fig. 570.—Box cover and ventilating grid.

In addition to the boxes described "pit channels" are made in the same six sizes and differ from the boxes in the absence of the "legs." A pit channel occupies less space for storage, but it requires more bricks in building, whilst the frame is cheaper than a box body on account of the smaller weight of iron. In every case the lips of the lids fit within the edges of the frame, and stone edging is, therefore, unnecessary. The pit channel, which is now rapidly superseding the box body, forms the only type of jointing chamber which can be used where sufficient depth cannot be obtained for a box. In such cases the pipe may be brought much nearer to the surface, and a fairly satisfactory space provided.

It has not been found necessary, save in most exceptional cases, to provide ventilation. A form of ventilator with a small bucket to prevent the entrance of mud into the box is shown in Fig. 570. The device is in very extensive use by electric light authorities to prevent the accumulation of explosive gases in their underground chambers.

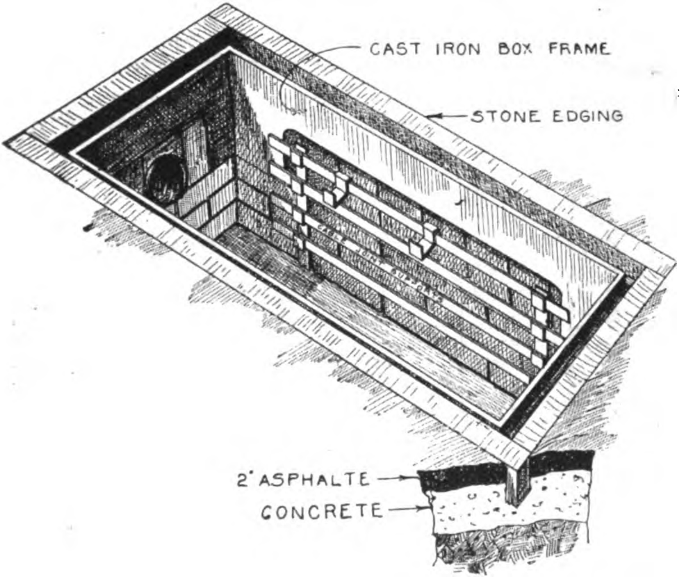


FIG. 571.—View of interior of a joint box showing the supports for cable joints.

MANHOLES.

Where there are several pipes, or at important junction points between main routes, manholes are constructed. They may be formed beneath the footway or the roadway, and for small sizes the former is preferable, since the lesser strength requisite can be obtained without undue expense. The manholes beneath the roadway must be capable of supporting the heaviest traffic, and are therefore of a heavier type. Usually the footways are largely taken up by gas, water, electric light, tramway, and other services, and space for a large manhole is not available.

The smallest type of footway manhole is built with reinforced concrete walls upon a 6″ concrete foundation, "rendered" with ¾″ of cement. A double-junction pit channel covers two-thirds of the top, while a reinforced concrete roof covers the remaining third.

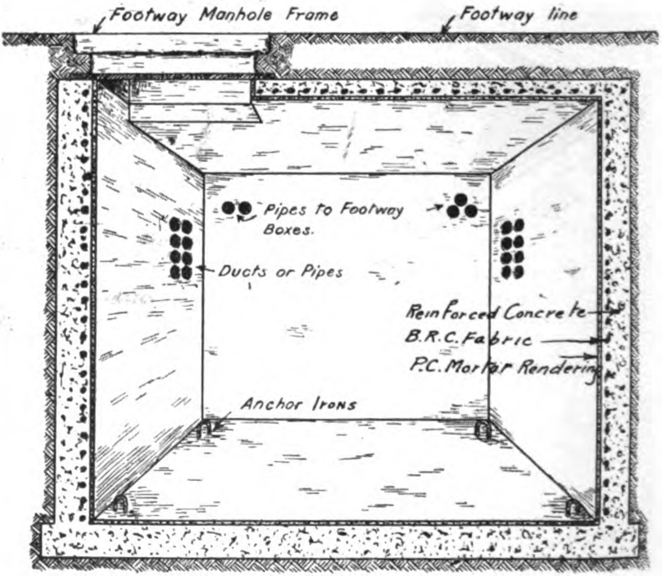


FIG. 572.—Footway manhole.

A larger type of footway manhole is illustrated in Fig. 572. The entrance is formed by adding a footway manhole frame or cover, the design of which closely resembles the single-junction pit channel previously described.

At each corner of the manhole ring-bolts or anchor irons are fixed to facilitate the operation of pulling the cable into the pipes. Galvanized iron steps are fixed into one of the end walls, as indicated in the figures. Iron cable bearers are provided to take the weight of the cables crossing the manhole. The entrance is invariably at the side of the manhole so that there shall be no danger of the cables being damaged by workmen stepping upon them, as might readily happen were the entrance placed directly over the cables.

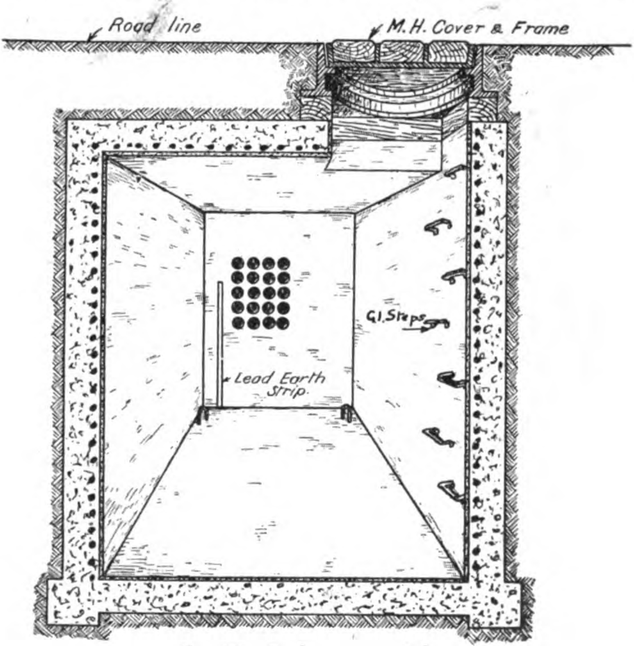


FIG. 573.—Carriage-way manhole.

When earthenware ducts are used the lead sheathings of the whole of the cables are joined with lead strip to the leaden earth plate, which is placed below the concrete foundation. The object of the arrangement is to prevent electrolytic damage to the cable sheathings produced by stray or return currents from electric tramway systems.

Roadway manholes are built in somewhat similar fashion, but the entrance consists of an iron frame and a cover fitted with wood blocks in the type of which an end view is given in Fig. 573. The reinforced concrete walls vary in thickness, those of roadway being thicker than those for footway manholes. The cables are supported upon cable bearers either bolted to the walls or fixed to the floor of the manhole, as shown in Figs. 574 and 575.

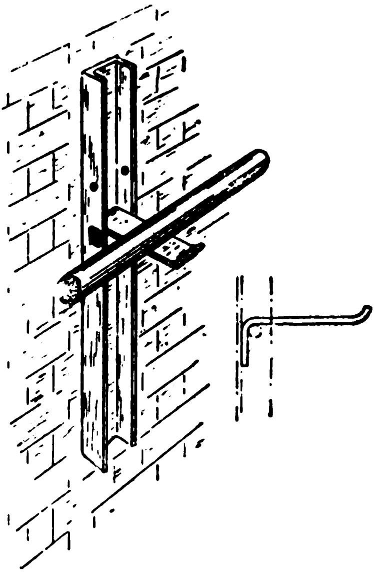


FIG. 574.—Cable bracket.

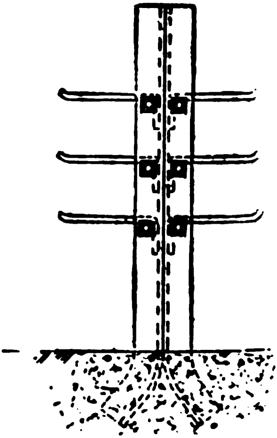


FIG. 575.—Cable bearer.

In flush boxes supports fixed into the brickwork at the side of the box are frequently used to support joints (see Fig. 571).

The material used for reinforcing the concrete roofs and walls is shown in Fig. 576. It is composed of longitudinal tensional members 3 inches apart, which are held in position by electrically welded lateral members of a smaller gauge, and which also key the tensional members when in the concrete (Fig. 577).

GUTTAPERCHA-COVERED WIRES.

At one time No. 7½ G.P. prepared wire was used for underground circuits ("7½" is the total gauge of the completed wire). The copper conductor is 50 mils in diameter, weighing 40 lbs. per mile, whilst the covering has a major diameter of 174 mils and weighs 50 lbs. to the mile. Single wires were spirally wrapped with ozokerit tape as a mechanical protection to the insulation, whilst quadruple cables are formed by spirally wrapping four untaped wires with a broad ozokerit tape.

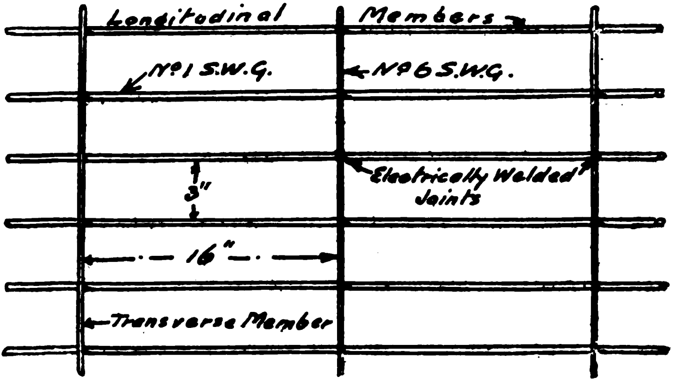


FIG. 576.—B.R.C. steel wire fabric. The material used for reinforcing the concrete manufactured by the British Reinforced Concrete Engineering Co.

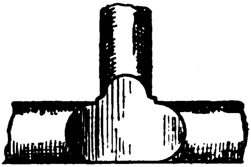


FIG. 577.—Section cut of electrically welded joint of the B.R.C. reinforcing material.

The disadvantages of guttapercha wires when laid underground consist in the cost, electrical inefficiency, and the deterioration which more or less rapidly sets in. The life of a guttapercha-covered wire is greatest when it is continuously under water, as in the case of submarine cables.* When exposed to the action of light and air the deterioration is rapid, and in underground pipes the wires are never wholly dry, nor are they wholly under water. Their life, under such conditions, is from 12 to 15 years, but is much less when high E.M.F.s are in use upon the circuits.

AIR-SPACE AND PAPER-CORE CABLES.

The air-space and paper-core cables now universally employed have the merits of cheapness and a lower electrostatic capacity than guttapercha-covered wires. For a given number of wires the cable itself is cheaper than the same number of guttapercha wires, and, as it occupies far less space, there is a large saving in the number of conduits needed. The net result is that the cost per circuit is one-third to one-fourth of that of a circuit in a guttapercha cable.

The carrying capacity of a pipe is proportional to the square of its internal diameter, but the design of the cables somewhat modifies this statement, since there are certain constants, such as the thickness of the lead covering, to be considered. It may, however, be interesting to compare the numbers of conductors of various types which may be accommodated within 2, 3, and 3¼ inch pipes, and the following table is therefore added—

Type of pipe.	G.P. wires 40-lb. conductors.		Number of wires in one paper-core or air-space cable.					
	Single wires.	Quadruple cables.	Screened 40 lb.	20-lb. conductors.	40-lb. conductors.	100-lb. conductors.	150-lb. conductors.	200-lb. conductors.
2″	40	10	61	122	74	38	30	24
3″	80	20	108	612	216	122	74	74
3¼″	92	23	156	612	254	150	96	74

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* See leading article, "Submarine Telephone Cables," in the *Electrician* of September 2, 1904, p. 796.

The cables consist of conductors contained within a seamless lead sheathing, and separated from each other by air and paper. The "air-space" cable is one in which the maximum amount of air space is allied with the minimum thickness of the paper, whilst "paper-core" cables are those in which the insulation is very largely of paper. For telephone distribution work a paper-core cable is employed, since the cost of the cable would be very greatly increased by enlarging the space occupied by each conductor. Again, the screened cable is of the paper-core type, since it is necessary to form a continuous copper sheathing around each conductor.

Cables of the two types described are frequently spoken of as "dry-core," "paper," or even "lead" cables, but the designations indicated above appear to be more accurate.

It will be obvious that the substitution of air for gutta-percha as the dielectric reduces the static capacity of the wires, and even in paper-core cables (see page 231) a very large reduction takes place. The capacity of paper-core *twin* cable conductors varies from ·08 with 20-lb. conductors to ·1 m.f. per mile with conductors weighing 100 lbs. or more per mile.

The most serious danger which menaces lead-covered cables consists in the corrosion of the sheathing, but this has not so far proved to be a vital danger. It will be obvious that from the very design of the conduits and boxes it is impossible to keep the pipes quite free from water. The water which finds its way into the pipes frequently contains active chemical substances in solution which gradually destroy the sheathing—in fact, there is evidence to show that in some cases a slight amount of chemical action commences even before the cable is pulled into the pipes, but this may be entirely avoided by the application of grease immediately after manufacture. Since the cast-iron pipe and the lead sheathing with a certain amount of impure water form a voltaic couple, corrosion may also arise from this source, but by far the most serious trouble is produced by leakage currents from the uninsulated return circuits of electric tramways. The precautions to be observed are as follows—

(1) To pack the boxlids with tarred pipe yarn and a mixture of crane grease and whitening so as to secure a water-tight joint.
(2) To use large quantities of petroleum jelly when drawing in the cables, and thus to provide a protective covering.
(3) To electrically connect the various lengths of iron pipe where they are broken by boxes or other jointing chambers, and to connect both the pipes and the cables which they contain to efficient earths at suitable distances apart.

Cases of corrosion are not so numerous now as they used to be. This is probably due to the extensive use of earthenware ducts and the liberal application of vaseline to the cable when being drawn in.

If the pipes are perfectly dry or if the cables are well covered with grease, chemical, voltaic, and electrolytic action is excluded, but in practice these conditions cannot always be attained. The object in bonding the pipes is to prevent any current circulating in the pipes from passing through the cables at the points where the line of pipes is broken by a jointing chamber, for it will be obvious that if moisture is present at these points electrolytic action must inevitably result. In some cases the effect has been of sufficient magnitude entirely to destroy the lead sheathing (by converting it into carbonate of lead or white lead) and thus exposing the paper insulation. In order to prevent electrolytic action due to leakage current in the cable sheath, where such current enters or leaves the cable, efficient earth connections at suitable points are provided.

The method of bonding the pipes together is illustrated in Fig 578. The spigot end of all new pipes is of slightly increased length so as to enable a suitable bolt hole to be made. A thin lead sleeve is slipped over the slightly conical head of the galvanized iron bonding bolt, whilst a washer, recessed to receive the lead strip used for electrically connecting the successive pipes across the jointing chamber, is placed beneath the nut. When this nut is screwed down, the lead between the pipe and the head of the bolt and that between the washer and the top of the pipe (which is, of course, previously scraped quite clean) is subjected to compression, thus establishing an intimate electrical contact between the pipe and the lead strip. For bonding the pipes which have already been laid, Bullers' patent clips are employed; they fit over the outside of the pipes and serve to maintain the lead connecting strip in firm and complete contact. Where there are several pipes in the one box, the ends of all the pipes are electrically connected together, and also to the various cables which they contain, by lengths of lead strip. It should be pointed out that the ordinary leaded joint (see Fig. 555) between the various pipes forms a fairly satisfactory electrical joint, notwithstanding the two coatings of Angus Smith compound which intervene between the socket, the lead, and the spigot of each pair of pipes.

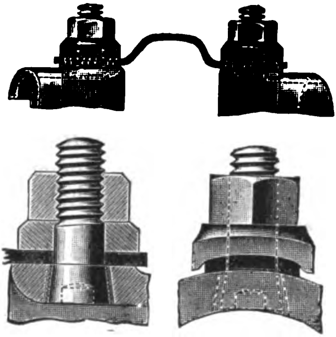
FIG. 578.—Bullers' bonding bolts.

INDUCTIVE DISTURBANCES.

The inductive interferences between parallel single-wire telephone circuits led to the universal adoption of metallic circuits. Owing to the unsensitive character of telegraph, in comparison with telephone, receiving apparatus no difficulty was experienced with single-wire telegraph circuits until they were brought into close proximity for long distances in air-space cables. In order to appreciate the nature and efficacy of the remedy it is necessary to investigate the typical conditions under which static and dynamic induction occur.

Consider three insulated brass spheres *A* *B*, and *C*, occupying the relative positions indicated in Fig. 579, *B* and *C* being joined by a wire. The sphere *A* is positively charged by connecting to it the positive pole of an earthed battery. The positive charge upon *A* acts inductively upon *B* with the result that a certain quantity of positive electricity is repelled along the wire to *C*, which becomes positively charged. The action of *A* upon *C* has been ignored since its effect is merely to reduce slightly the quantity of electricity flowing from *B* to *C*. When *A* is discharged, the negative charge upon *B* is no longer held by the positive charge upon *A*, consequently a current flows from *C* to *B*, and both spheres resume their normal or uncharged conditions.

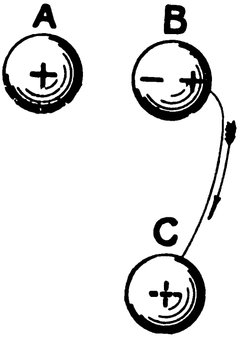

FIG. 579.—Electrostatic induction.

Consideration will show that every change in the charge *A* produces a current between *B* and *C*. An increase in the positive charge or a reduction of the negative charge causes a current to flow from *B* to *C*, whilst a reduction of the positive or an increase in the negative charge produces a current from *C* to *B*. The induced current only flows whilst the charge upon *A* is varying.

The connection of an earthed battery to the disconnected line *A* (Fig. 580) produces currents through the ends of the earthed circuit *B* which is parallel to it. The line *B* becomes negatively charged by the repulsion of a certain quantity of electricity to earth at either end of the circuit. A reversal of the battery, of course, produces a current flowing into the wire from earth at each end. If a relay is joined up at each end of the earthed circuit, and the disconnected wire is joined to a double current set, the signals sent on the key may be read upon the two relays, by carefully adjusting them to neutrality. For example, suppose that the letter "*T*" is sent. The spacing current charges the disconnected circuit negatively, which causes currents to flow from earth through the relays into the line, so causing the tongues to go over to *S* or leaving them in that position if already upon the left contacts. The depression of the key for the dash charges *A* positively and currents flow through the relays, in the direction *U* to *D*, to earth at each end. This commences the mark which is not stopped until the key is released and momentary currents again flow through the relays.

This is a typical case of electrostatic induction, and it is to this effect that the whole of the serious trouble is due.

Electro-magnetic, or dynamic, induction is due to the fact that the lines of force generated by a current in the first circuit cut the conductor, and so induce a current in the second.

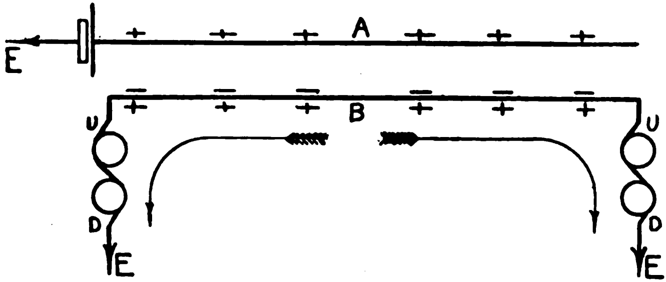

FIG. 580.—Electrostatic induction between two telegraph circuits.

In Figs. 580 and 581 the relays are all shown with their "up" sides joined to line, whereas in practice the relay at one end would have the "up" side to earth. It will therefore be realized that the inductive effect would be such as to produce reversed signals at the up station.

Two parallel earthed circuits are shown in Fig. 581, and this represents the case which arises in practice. When the battery is connected to circuit *A* a current begins to pass along the line, and the wire is charged as indicated by the shaded triangle. Now the charge upon *A* produces momentary currents in the directions shown by the double arrow heads, but as the charge is larger at the sending end the current produced through the relay on the left is greater than that through the right-hand relay, the actual difference being in the ratio of two to one.

Whilst the current is attaining its full value the concentric lines of force round the full length of *A* cut through the circuit *B*, generating an E.M.F. in the direction shown by the single arrow heads. The value of the resulting induced current is, of course, equal at all parts of the circuit.

At the left-hand side of the circuit the dynamic and static effects add together, but at the other end they oppose, with the result that this end of the circuit may be practically unaffected, whilst pronounced currents are produced through the left relay whenever the position of the key upon *A* is altered.

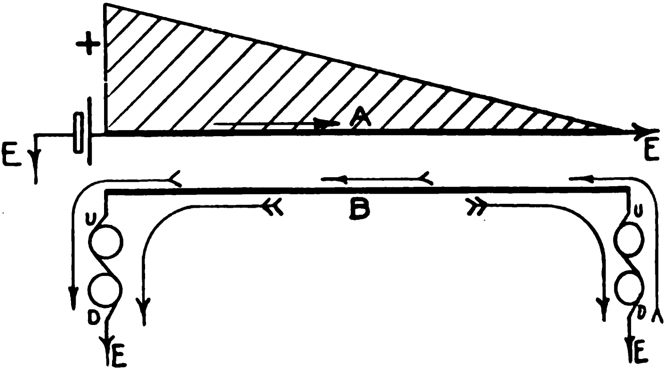

FIG. 581.—Electrostatic and dynamic induction between two telegraph circuits.

By considering a few typical cases it can readily be shown that the interference by induced currents is much greater at the end nearer the sending station than at the further end.

In the original London-Birmingham underground cable the inductive effect of the circuits upon each other is so great as to render Wheatstone working upon single wires quite impracticable, and this notwithstanding that the wires are crossed at frequent intervals so as to prevent any two circuits from running side by side for any considerable distance. The wires in this cable are twisted in pairs, and for each Wheatstone circuit a twisted pair of wires is employed, but this is not a very serious matter, since a key-worked duplex circuit is superposed upon each Wheatstone circuit, and two circuits are thus obtained from the pair of wires. (See Appendix D.)

By twisting the wires in pairs the inductive effect of each wire is balanced by the opposite effect of its partner, whilst no effect can be produced upon the twisted circuit, owing to the two wires uniformly changing their positions with such frequency that the inductive effects in each are equal and balance.

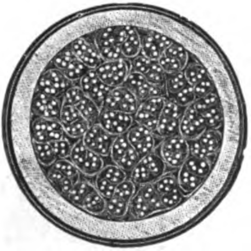

Fig. 583.—Section of a quadruple pair cable.

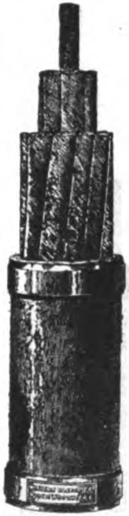

Fig. 582.—Quadruple pair air-space cable.

A long series of very exhaustive experiments proved that a certain amount of inductive interference occurs between two neighbouring pairs of twisted wires of equal lay running together for a considerable distance. This induction is of a serious character when the pairs of wires are used for telephone circuits, but the sphere of disturbance due to each twisted pair is limited to the two, or in some cases three, pairs next to it upon either side. This defect has been remedied by varying the lay, *i.e.* the length taken for a complete twist. With 20-lb. conductors, the successive conductors in the outer layers have lays of

3, 4, 5 and 6 inches respectively, whilst with 100-lb. conductors the lays are 7, 8, 9 and 10 inches.

SCREENED CABLE.

As stated, the use of a metallic circuit for the high-speed wires eliminates all trouble due to inductive interference between the telegraph circuits contained within a long cable. In order to avoid the use of two conductors for each Wheatstone circuit, and effectually to prevent inductive disturbances, even when the circuits run together in the same relative positions for long distances, the "paper-core screened single conductors" cable was specially designed.

The conductor, of 40-lb. copper, is first covered with three wrappings of paper, the first of which may be either spiral or longitudinal, but the other two are invariably applied spirally. The spiral wrappings are applied so as to form a helical air space throughout the length of the core. The conductor thus insulated is then enclosed in a final wrapping of paper forming a closed helix without overlap. Over this is laid a helical winding of copper tape 300 mils wide and 3 thick, with an overlap of 90 mils wide. The overall diameter of each completed conductor is 160, 180, or 200 mils, according to the type of cable required. For instance,

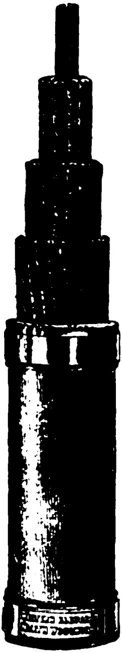

FIG. 584.—Screened conductor cable.

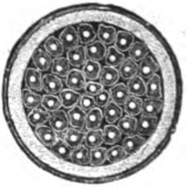

FIG. 585.—Section of a screened conductor cable.

a cable containing 40 conductors is made up of 1, 6, 12, and 21, cores in the centre, 1st, 2nd, and outer layers respectively. The outer layer conductors are in this case 160 mils in diameter, whilst all the remaining cores have a diameter of 200 mils. The capacity of the 160, 180 and 200 mil cores are respectively ·15, ·135 and ·125 m.f. per mile, whilst the minimum insulation is specified as 5000 megohms per mile at 50° F. after one minute's electrification.

The whole of the cores are laid together, and a seamless cylindrical sheathing of lead, at a temperature of 600° F., is applied to the cable. The thickness of this sheathing is from 130 to 150 mils, with an external diameter of 1·65 inches.

The cable is made in the lengths required for pulling in between the various boxes along the route upon which it is to be used. The two ends of the cable are sealed by soldering lead caps on to the ends of the sheathing, and the completed length is wound on to a wooden drum ready for delivery.

Although this description relates to a particular type of cable, it is typical of all, since the differences consist merely in the number and arrangement of the cores.

A cable having forty-five 40-lb. conductors is illustrated in Figs. 582 and 583. A 40-lb. conductor core having a diameter of 230 mils gives a capacity of ·095 m.f. per mile. Cores having 70 lb. and 100 lb. and even larger conductors are used, but they are very often specially designed to meet the particular circumstances under which they are to be employed. A 70-lb. core with a total diameter of 225 mils and a 100-lb. core with a diameter of 240 mils each give a capacity of ·125 m.f. per mile.

The substitution of paper and air for the guttapercha covering of the old type of wire reduces the capacity, and increases both the insulation resistance and the dielectric strength of the core. The addition of the copper tape screens the conductors from inductive interference, and so obviates the difficulty which arose with the ordinary type of air-space cable, when used for telegraph circuits.

The copper tape forms a continuous conducting tube around the wire, and as this tube is earth-connected, either by direct contact with the lead sheathing or indirectly by the tapes of the other cores, it will be obvious that electrostatic induction between the wires cannot occur. First, Faraday's experiments showed that variations in the differences of potential existing or produced between conductors within a metallic covering produce no effect outside that covering. Secondly, any source of inductive disturbances brought to bear upon a screened conductor produces the whole of its effect upon the copper tape. The magnetic lines of force induce currents along the tape covering the wire, and as this path is highly conductive, practically the whole of the energy is absorbed by it. In order to produce an inductive effect, currents must be generated in the tape of the disturbing wire and also in the tape of the disturbed wire before the second conductor is reached. It will therefore be realized that the energy available is exceedingly small,

Practical experience of long screened cables revealed the fact that the arrangement was by no means perfect in preventing induction. It has been found that an ordinary twisted pair gives equally good results when one wire is used as the working circuit and the companion wire of the pair so used is earthed at each end of the cable. Thus the standard twisted pair telephone cable may be used for telegraph circuits and, if later, it is found to be practicable to divert or to give up the telegraph circuits, the cable can be used for telephones. By the interpolation of thermionic relays in telephone trunk lines

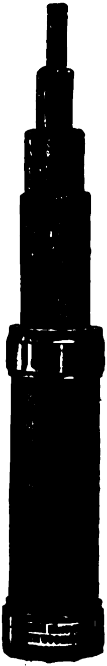

Fig. 586.—Section of a twin cable.

Fig. 587.—Twin paper core cable.

carried in underground cables, much smaller conductors can now be used and it is probable that in future the largest gauge conductor used will not weigh more than 50 lbs. per mile. Research has shown that by working telegraphs with small battery power (of the order of 24 to 40 volts) on twisted pairs, both telegraphs and telephones may be worked in the same cable without serious interference by the former with the latter.

There is a very large number of types of cables used by the Post Office, and as telegraph and telephone circuits are frequently contained within a single cable it is desirable briefly to indicate a few of the prototypes.

Air-space cables. Twin types.—In every case the variable lay principle is adopted, and the various cables differ solely in the number of pairs, gauge of the conductors, and consequently in the diameter of the cable (Figs. 586–587).

Air-space cables. Quadruple pair type.—Four pairs of wires are twisted together round a jute centre or core and the cable formed of the required number of these quadruple pairs (Figs. 582 and 583). The lay of the four pairs of wires in each set is varied, as also is the lay of the quadruple cores. The advantage gained by this construction lies in the fact that telephone trunk line superposing is practicable upon the quadruple pairs, and that the wires in each 8-wire core may be combined to form heavy-gauge circuits. It is, however, giving way to the multiple twin type.

Composite cables.—The various methods of arranging the conductors are sometimes utilized to provide for special requirements. For instance, 42 wires of 150-lb. and 48 of 100-lb. gauge are combined to form a cable in the following way. A central pair of 150-lb. wire forms the core, and around it are placed four paper-wrapped cables, the interstices being filled by single, or, as they are termed, "worming pairs." Each of the paper-wrapped cables consists of four quadruple pair 150-lb. conductors with four twin 100-lb. conductors filling the spaces between the 150-lb. pairs—the latter having a large air space.

Again, cables are formed having a core of multiple twin or quadruple pairs surrounded by screened conductors for telegraph circuits. For example, one such cable contains eight 150-lb. and fifty-six 100-lb. wires arranged in quadruple pairs together with thirty 100-lb. and seven 40-lb. screened conductors. The centre is formed by one 150-lb. quadruple pair core around which are placed seven 100-lb. quadruple pair cores, whilst the outside layer is formed by the thirty 100-lb. screened conductors, between which and the 100-lb. quadruple twin cores are the seven 40-lb. conductors.

Multiple twin cables.—In these cables the conductors are first twisted in pairs, and two pairs are then twisted together. A second set of two twisted pairs is twisted with the first set. In some cases the complete group is twisted with a similar one. The object attained is that the conductors may be bunched to provide a circuit of heavier gauge. For instance, with 40-lb. conductors the equivalent of 80 lb. and 160 lb. is obtained by placing the wires of one and two pairs respectively in parallel to form one wire of the new circuit. The capacity is increased by bunching but in a smaller ratio than the resistance is reduced, hence the KR of the bunched circuit is less than that of a single pair. The variable lay principle is adopted to prevent overhearing, and the length of the lay is distinguished by the colour of the paper wrappings over the 2, 4, 8, and 16-wire cores, the A and B lines being distinguished by the colour of the spiral wrapping of thread. Since the conductors are all twisted up in the manner described, the bunched wires are still twisted together and inductive disturbances eliminated. By superimposing it is theoretically possible to obtain 15 circuits from each 16-wire core.

CABLE LENGTHS.

It is economical to manufacture lead-covered cables in long lengths, but the length which may safely be placed upon a drum for transportation should not be such as to cause the weight of the filled drum to exceed three tons. When this limit is passed the weight of the drum is likely to damage the paving along which it may have to be rolled. The length of cable which may be pulled into the pipes in one operation depends upon the weight of the cable per unit length, its diameter, and also upon the character of the route. Where the route is either straight or the curvature slight, the standard length is 176 yards from centre to centre and the maximum 200 yards.

PULLING IN LEAD-COVERED CABLES.

It will now be possible to follow the various operations involved in pulling in the successive lengths of lead-covered cables.

When a draw wire has been provided, as explained on page 858, this is used for pulling in the rope. If there is no draw wire, sweeps' rods of special construction are pushed through the pipe. These rods are of malacca cane, and are provided with a screwed brass socket and trigger at one end and with suitable screwed fitting at the other. A rod is passed into the pipe, and a second length screwed on, and automatically locked by the spring trigger which prevents the rods from unscrewing whilst being pushed through the pipe. As each rod is pushed up the pipe another is added, until finally the two jointing chambers are linked by a continuous length of rods. The rope is next attached and pulled through by withdrawing the rods.

It will, of course, be obvious that in these, as in the subsequent operations, it is necessary to rail off a suitable space for carrying out the work, in order that pedestrians may neither impede it nor run any risk of injury. Where holes are left the guards must be supplemented by lamps at night

The next operation has for its object the cleaning and testing of the pipe into which the cable is to be drawn. The rope is joined to a mandrel, a circular brush about 12 inches long and a piece of cable roughly 5 feet in length and of a diameter very slightly less than that of the pipe. For example, with a 3-inch pipe a length of $\frac{216}{40}$ cable would probably be used. This piece of cable is painted over, and the whole train, followed by a second length of rope, is pulled through the section. The test cable is carefully examined for any trace of damage, and when this occurs the defect is, of course, remedied before the new cable is pulled in. The position of this defect is usually apparent from the extra stress which has to be exerted to pull the test cable and mandrel past it.

The rope used for pulling in the cable is usually of the 3-inch size (*i.e.* the circumference is 3 inches), and when new has a breaking stress of about 35 cwt. which ensures that it may with safety be used in all cases in which the stress does not exceed 9 cwt. if the rope is new or 6 cwt. if old but in good condition.

The drum containing the length of cable is conveyed upon a low wagon or "float" to the box from which it is to be paid into the pipe. The battens are removed, the drum rolled into position, and a steel spindle passed through the holes in the centre. It is then raised upon lifting-jacks sufficiently to permit it to revolve freely. The manufacturers usually seal the cable by soldering circular discs of lead to the ends, and as this is scarcely calculated to withstand the stress placed upon it by the clip, it is advisable to remove it and make up the end in a stronger manner. When this has been done the grip is fixed on to the cable.

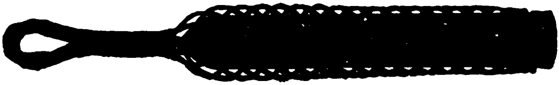

FIG. 588.—Cable grip.

The "cable grip," illustrated in Fig. 588, is constructed upon the principle of a well-known puzzle toy. The lead sheathing at the end of the cable is beaten down on to the conductors with a boxwood dresser so as to prevent the lead sheathing from taking the whole of the stresses which result during the pulling-in process. The grip is passed over the prepared end of the cable, to which it is lashed as indicated. The effect of stress applied to the loop is merely to tighten the grip of the latticed wires upon the cable. In this way the need for cutting away the end is obviated, and the saving of even a foot of cable at either end of each length represents a considerable sum of money where long lengths of large cable are concerned. A suitable form of sleeve is used to protect the wire cable grip, which is naturally subject to considerable wear by friction with the pipes through which it is pulled.

The clip, having been attached to the cable, is joined to the pulling-in rope by means of a Keystone connecting link (Figs. 589 and 590) connecting the loop of the clip and the ring upon the rope.

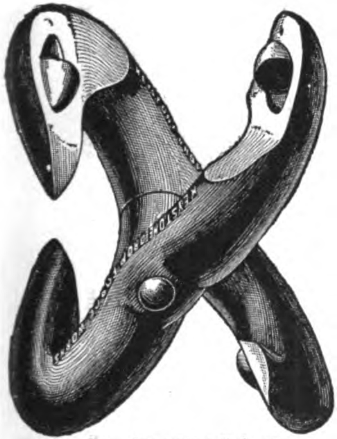
FIG. 589.—Connecting link, open.

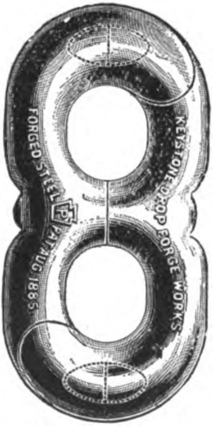

FIG. 590.—Connecting link, closed.

Whilst these preparations are being made the winch is placed in position and the rope given three or four turns round the barrel. Where the pulling in is done from a manhole a snatchblock attached to the rings in the floor (see Fig. 591) is placed upon the rope to prevent chafing upon the edge of the pipe and manhole entrance. In Fig. 591 a winch worked by a small water-cooled petrol motor is shown, and in Fig. 592 a motor winch of the type at present used by the Post Office * is illustrated.

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* Portable petrol-driven winch by J. G. Hines. *P. O. E. E. Journal*, Vol. II. p. 810.

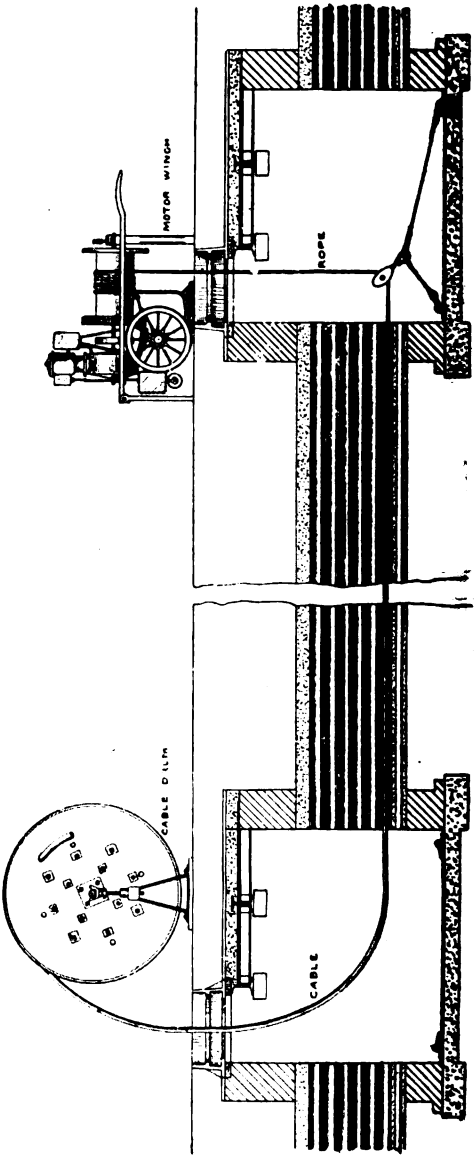

FIG. 591.—A dry core cable in course of drawing-in by means of a motor winch (not P.O. pattern).

The cable drum is now twisted and the cable bent into a curve of wide radius, and the end placed within the pipe, the slack rope being taken up from the distant end. The actual pulling in of the cable now commences, and with large cables four men are required for turning a hand winch. Men are deputed to revolve the cable drum carefully and bend the cable so that it enters the pipe without injury to the sheathing.

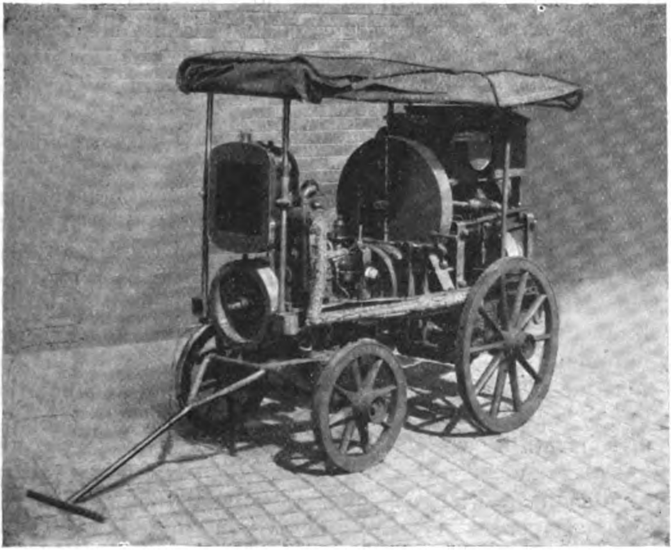

Fig. 592.—Motor winch.—(The warping drum at the right-hand end of the truck.)

In all these operations the guiding principle is to deal with cable just as though it were a hollow tube of lead.

As the cable passes into the pipe it is heavily anointed with petroleum jelly, which acts as a lubricant, thus reducing the friction between the cable and the pipe. Since the clip end of the cable has to be drawn through the whole length of the pipe, whilst the last yard of cable is only drawn through one yard of pipe, the quantity of petroleum jelly spread upon the cable is gradually reduced as the pulling in proceeds.

When the cable has been pulled in as far as possible, *i.e.* when the end of the rope reaches the snatchblock, the length of cable projecting from the pipe is usually insufficient to admit of jointing, and it is therefore necessary to remove the clip and obtain a fresh purchase upon the cable. This is accomplished by placing a split grip over the cable and lashing the pulling rope along the 12″ of the grip as near to the pipe as possible. In this way the extra yard or so of cable may readily be obtained, it sometimes being necessary to move the grip back once or twice to obtain the requisite length of cable in the jointing chamber.

After the cable has been pulled in, the clip is removed.

When the cable has to be pulled into joint boxes a snatchblock or pulley is securely lashed to a balk of wood placed at the bottom of the box and wedged in position by timber placed along the floor of the box and held down by two upright pieces of wood bearing upon the two planks placed over the box to carry the winch. If this arrangement were not made it would be necessary to remove the box, open out the ground, and back-stay the winch in order to avoid a heavy upward pull upon the pipe.

In arranging the length of the cable drawn in, provision must be made for the end damaged by the clip, and for a sufficient overlap for jointing. Usually one per cent. above the centre to centre mileage is an ample provision.

Other considerations being equal, it is preferable to pull the cable in in the direction in which the pipes are laid, *i.e.* in the direction of spigot to socket, since there is thus no chance of the clip wedging against the spigots.

Where there is a curve in the route the cable should be pulled in from the end nearest to the curve, since the shortest possible length of cable is thereby pulled round the curve. Again, it obviously requires less force to pull a cable through a pipe having a downward gradient than to pull it upwards, and therefore when the route is hilly, advantage may be taken of this fact.

It is always desirable to pull the various cables in in the same direction, so that the direction of the lay may be the same upon both sides of each joint.

JOINTING LEAD-COVERED CABLES.

A gothic-shaped tent, consisting of canvas mounted upon a wooden frame, is erected over the box or hole in the ground where the joint is to be made, and in order to avoid any risk of fire, the spirit lamp used for soldering, etc., is held in position by springs and is surrounded by a metal shield which is secured to the tent. In the case of roadway manholes a circular guard is placed round the entrance, and, as a further precaution, a man is stationed by it during the whole of the time that it is open. Similar remarks apply to the execution of work of every description.

The cables are cut so as to leave the amount of overlap required for the joint. This varies from 10″ with very small, to 2′, or even more, with large cables. For instance, a $\frac{14}{20}$ cable would require 10″, a $\frac{74}{40}$, 15″, and $\frac{216}{40}$, 24″. First of all, the surplus length of cable is cut away and then the sheathing is cut rather more than halfway through with a knife, and a longitudinal cut from the end of the cable to the point at which the sheathing is to be removed is made. It is then *torn* away with a pair of pliers. The effect of this procedure is to form a bevelled edge upon the inner edge of the sheathing. This leaves the conductors upon each side exposed and of sufficient length to reach to the point at which the lead sheathing ends upon the opposite cable. A lead sleeve of the requisite length and diameter is then passed over one end of the cable and pushed up the pipe so as not to impede the operations now to be described. In each cable the wires are separated, tied up in half layers and bent up at right angles to the cable. The jointing of the conductors then commences, starting with the lower wires in outer layer, then the lower wires in the next layer, and so on until the lower half has been dealt with. The upper wires are next jointed, but this time working from the centre outwards.

The method of jointing varies with the type of cable, and two illustrations typical of the rest will be given: First, a multiple twin cable, with conductors of 70-lb., 100-lb., 150-lb., or 200-lb. gauge, in which each wire is loosely but completely enclosed within a paper covering served with a wrapping of thread, having a long lay. Secondly, a multiple twin cable, with 40-lb. conductors.

In the first case (Fig. 593) the spiral wrapping of paper which encloses both wires is tied and removed to that point; the spiral thread on each of the two wires to be jointed is unwrapped to about two inches from where the conductors are to be cut, and the thread is tied over the paper. One of the loose threads is then cut off, while the other, about 12″ long, is retained.

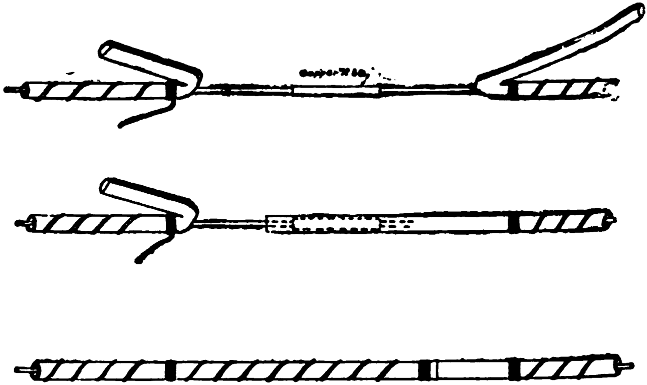

FIG. 593.—Method of jointing 100-lb. conductor cables.

The paper is unwrapped to the point at which the thread is tied, and cut so that the remaining length will overlap the centre of the joint about 1½ inches.

The conductors are cut so that they abut when brought together, the ends are cleaned with glass paper, inserted in a tinned copper jointing sleeve, and soldered with resin as a flux.

The paper end without thread is then replaced over the joint, the other paper end is wrapped over it and the 12 inches of thread is now wrapped round the paper and tied.

In jointing 40-lb. and lighter conductors the two wires should be given three or four twists in a length of ½″ with the paper insulation intact upon both wires (Fig. 594). At the end of this preliminary twist the paper is removed, the conductors cleaned, twisted, and the surplus wire cut away, leaving 1⅛″ of twisted conductors. This twisted joint should be made without the aid of pliers since possible injury to the conductors is thereby avoided; a skilled jointer is able to make the joint with ample tightness and security, and the practice of giving the joint a final twist with the pliers is deprecated.

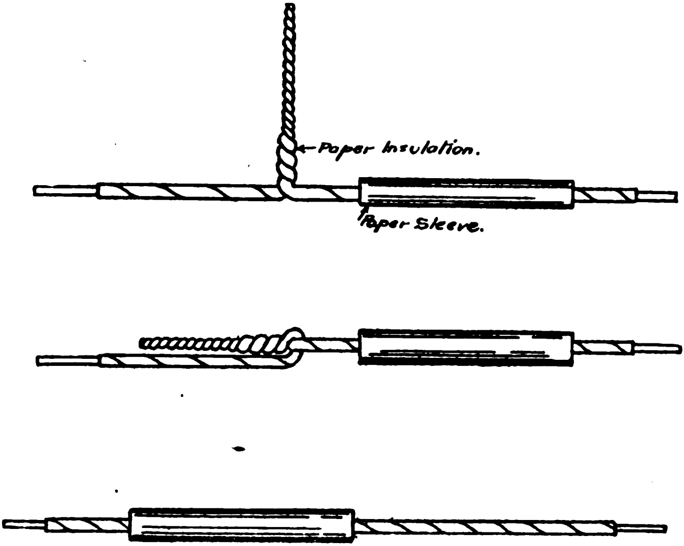

FIG. 594.—Method of jointing 40-lb. conductors.

Joints between 40-lb. conductors, or conductors which are to be impregnated with compound are soldered.

In all the later types of twisted cable the length of the lay is indicated by the colour of the paper wrapping which encloses each 2, 4, 8, or 16-wire core as the case may be, the A and B wires of each pair being distinguished by the colour (red for A and white for B) of the spiral wrapping of thread upon each single-wire core.

Consideration will show that if the whole of the conductor joints are made at one point, the resulting joint will be of an extremely bulky description, and that the sleeve would take the form of a spheroid. This is, however, readily obviated by carefully spacing the joints, and, generally speaking, the diameter of the final paper wrapping does not greatly exceed that of the lead sheathing of the cable itself.

In some cables there is no serving of thread over each single wire, but the method of jointing is scarcely affected by this variation. It is, of course, essential that great care should be taken to join each pair of wires through to another twisted pair, since the result of a mistake is to destroy the advantage of the twist.

The paper sleeves are placed within a circular tin box resting within a bucket which is warmed by the flame of a spirit lamp placed beneath it. This ensures that the sleeves shall be perfectly dry, since the bucket, etc., is kept under cover within the tent or manhole. When the last joint has been made the wires are thoroughly dried with a charcoal brazier, or, where the confined space would cause the fumes to be felt, hot powdered quicklime may be laid over the conductors. The test for dryness consists in holding a cold mirror upon the joint, which is not sufficiently dry until not a trace of moisture is observable on the glass.

Recently, experiments have been made by boiling out or drying out the joints with paraffin wax heated above the boiling point of water (to 250°F.). The conductors are opened out as soon as the cable is uncapped and the wax is poured over them at such a temperature that it all runs off with the exception of a thin film left on the conductor and leaving the paper insulation as "grease paper." This effectually prevents a lowering of the insulation during testing and jointing due to the atmosphere and the natural moisture of the jointer's hands. The air space is maintained by the procedure described and the joint does not become solid—a condition which if permitted would effectually stop the passage of dry air through the joint when desiccating the cable.

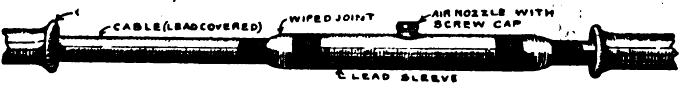

FIG. 595.—Completed joint.

The joint is then spirally wrapped with paper, but a hole is cut in the paper at the point below the air nozzle upon the lead sleeve. The lead sleeve is next pulled over the joint, and is secured to the sheathing upon either side by plumbers' wiped joints (Fig. 595). The "wipe" should be quite uniform and without any trace of eccentricity, and, of course, perfectly homogeneous. The heat applied during the "wiping" usually expels any remaining traces of moisture through the open air nozzle.

JOINT TESTING AND DRY-AIR PLANT.

The wiped joint is tested by means of a portable desiccator mounted upon a truck. It comprises an air pump worked by a suitable handle or in some cases by a small petrol motor. This draws air from the atmosphere, and finally pumps it through cylinders containing calcium chloride into the cable, which is connected to it by means of a length of flexible tubing screwed on to the air nozzle. The joint is smeared with soapsuds or glycerine, and the pump is worked until a pressure of 20 lbs. to the square inch is indicated upon the gauge. The joint is meantime closely examined for any trace of air bubbles, the presence of which would indicate a defect in the wipe. This test is a severe one, and it may be said that a defective joint cannot possibly be overlooked. The opening of the air nozzle is next closed by soldering on a tinned disc, and finally screwing the air nozzle cap on, so completing the joint.

The pressure test of a section of cable is made by raising the pressure to 20 lbs. throughout the cable as shown by the pressure gauges at each end. The cable is then left for twenty-four hours, when, unless the pressure is at least 18 lbs., the cable is considered defective and the source of leakage traced.

A defect in the sheathing would be indicated by a leak which occurred whilst the whole of the joints had been found to be perfect. By successively claying up the space between the cable and the pipe at both ends of each section, and by making a pinhole through one side of the clay and covering it with glycerine or soapsuds, the section in which the fault exists will be made apparent by the leakage of the air, pumped into the cable, through the pinhole in the clay.

If the joint test is made by filling the cable to a pressure of 20 lbs. and successively examining the various joints, any leakage will be shown by a fall of pressure.

The advantage of the dry-air plant lies not only in joint testing, but also in the fact that any trace of moisture may be expelled by pumping dry air through the cable. This is the object of the calcium chloride, which is highly hygroscopic, and serves to remove every trace of moisture from the air which passes over it. Of course, it is necessary periodically to renew the calcium chloride.

When desiccating a cable it is best to restrict the rate at which the air passes through the cable, and this is accomplished by fixing an escape valve to the air nozzle at the end of the section and setting it to blow at 8 lbs. It is preferable to place the desiccator in the centre of the section to be dealt with and to blow each way rather than to place it at one end. All cable heads are provided with a gas plug, by removing which and coupling up an escape valve the process of desiccation may be carried out.

At many of the larger offices, and at all London telephone exchanges, an electrically driven dry-air plant is permanently installed. A view of such a plant is shown in Fig. 596, from which it will be observed that the air

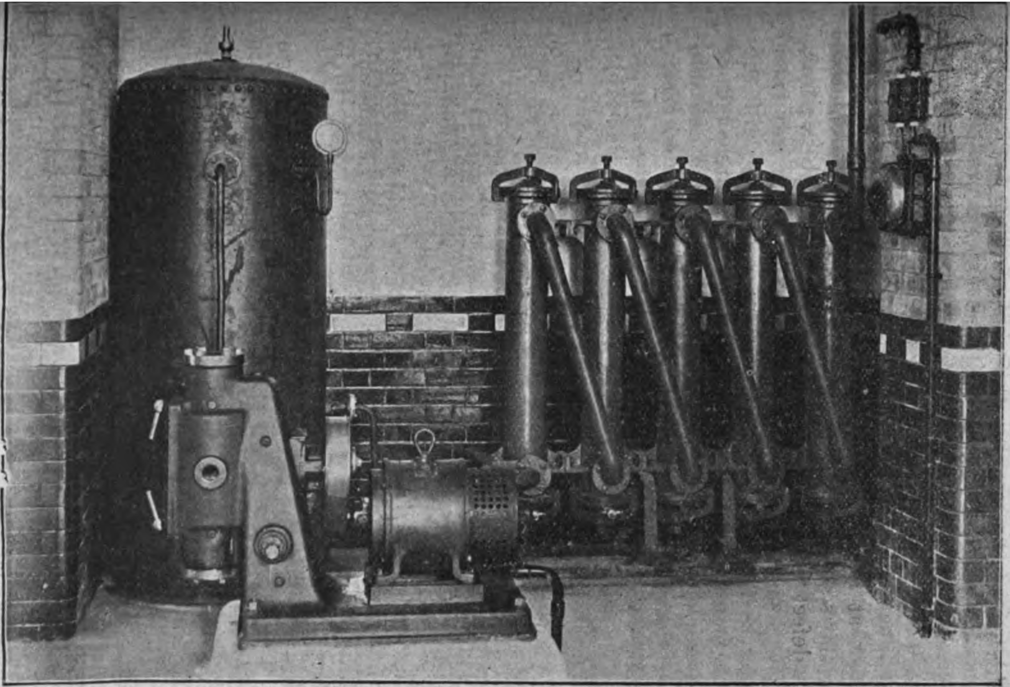

FIG. 596.—General view of an electrically driven dry-air plant.

is passed through a container and finally through the cylinders on its way to the cables. The duplex compressor or pump is driven by a 2 H.P. motor, mounted upon the bed plate. Escape or safety valves set to blow at 20 lbs. are provided both upon the motor and the container, which latter also carries a pressure gauge. The desiccator consists of five cylinders, within each of which is placed a muslin bag containing the calcium chloride. In large telephone exchanges the dry-air supply is permanently connected to every cable, a tap being interposed upon the branch pipe.

A motor desiccator,* driven by a small single cylinder water-cooled petrol motor, mounted on a truck, is extensively used for testing and drying cables remote from a stationary plant.

ELECTRICAL TESTS DURING CONSTRUCTION.

The cable is subjected to a series of electrical tests after each joint has been completed, the objects gained being to prove (1) that the insulation of the wires is maintained, (2) that contacts and disconnections do not exist, and (3) that the wires have been correctly jointed: for example, with a twin-wire cable it is essential to prove that the two wires of each twisted pair are jointed through to the two wires of a twisted pair, *i.e.* to ensure that the two wires forming a pair are twisted together throughout the length of the cable.

These tests may be readily made if the cable is first jointed to a cable connection box, or is fitted with a cable distribution plug. Lengths of indiarubber-covered wire are soldered to "insulated pin-connectors" which serve to connect the leads to the pins in the cable connection box. The other ends of these leads are passed through holes in a board and the ends bared. By arranging in rows those wires which may be tested together, and by furnishing a terminal for each row, the actual tests are greatly facilitated. The bared ends of the leads are connected with very fine tinned copper wire (No. 30) in rows to the terminals which are normally earthed. To test any particular group the fine wire is taken from the terminal and connected to the testing lead whilst leaving the remaining wires to earth. The board must be perfectly dry and there should be no leakage upon the testing leads. Where such leakages exist they will usually be found to occur at the surfaces of the bared ends of the various leads.

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* "Desiccators," by J. G. Hines. *P. O. E. E. Journal*, Vol. IV. p. 262.

When the first joint has been made, the lead covering at the end of the cable is removed and the wires carefully separated, and, if necessary, all traces of moisture removed by means of braziers. The insulation test is then made as indicated above. The cable is tested as each joint is completed, and any defect is therefore discovered with promptitude and certainty. The minimum insulation resistance during construction may be as high as 5000 megohms per mile—a value which is only attained when scrupulous care as to dryness is observed.

The test for continuity and correct jointing is usually made by exchanging "beats" upon detectors, thereby ensuring that the wires have been correctly paired, and also that pairs have not been crossed between the various layers. It is, of course, quite possible to cross a pair in, say, the outside with one in the next layer, but at the subsequent joint these two pairs may be at opposite sides of the cable.

With short lengths of cables containing a very large number of wires the systematic tests described are scarcely practicable owing to the time occupied. It will, therefore, usually suffice to make a single set of tests upon completion of the work, or, if desired, the joints may be made and tested in sets of three. The following procedure is, however, to be preferred: The wires are looped in pairs at the cable connection box or test frame, and the jointer may then prove his own pairs, or the work may be done by a foreman. The insulation test is taken after each test of three consecutive joints has been made. A fairly reliable rough test may be made by occasionally testing a few of the wires in the outer layer.

It is generally of considerable advantage to provide a means of communication with the jointer, and this is done by furnishing him with a portable telephone for connection to one of the pairs.

The maintenance testing of a working cable is accomplished by taking out one pair of wires upon the outside layer and specially connecting them with rubber-covered wires, so that there is no leakage upon the leads. The periodical tests of these wires are usually a sufficient index to the insulation of the cable. It would scarcely be practicable to make the series of tests already described without causing serious delay to the traffic, or without a considerable amount of Sunday work, both of which courses are equally objectionable.

TERMINATION OF CABLES.

The cable is carried to a point within a few feet of the main distribution frame. It is there connected to a suitable length of lead-covered cable of similar formation but with conductors insulated with silk and cotton and impregnated with beeswax. This effectively seals the office end of the cable. At the main distribution frame the lead covering is removed from the silk and cotton covered cable, and the wires are laced out on the line side of the frame, the ironwork of the frame being served with adhesive insulating tape at all points where the laced cable is attached. See also p. 717.

CABLE CONNECTION BOXES.

Where it is necessary to provide testing and cross-connection facilities at intermediate points on very long underground routes, cable connection boxes are fixed in pillar test boxes or attached to walls. The present tendency is, however, to dispense with such arrangements as far as possible, owing to the source of weakness which they introduce into the cable.

A cable connection box fitted to receive the two sides of a 54-wire cable, such as is used in pillar test boxes, is illustrated in Fig. 597. It consists of a cast-iron box with two lids divided by a central diaphragm, through which pins, insulated with ebonite, are fixed, so as to be perfectly air tight, whilst affording electrical connections between the two compartments. The two cables are passed through the gun-metal linings and plumbers' wiped joints are made between the sheathings and the linings. The lead is stripped off the lengths of cable within the box, and the wires are soldered to the connection pins. When this has been done the wires are thoroughly dried by means of braziers, and the lid fixed by nuts and bolts, the design of the lid and the linings being such as to secure a perfectly air-tight joint. The two cables are connected by short lengths of insulated wire soldered between the pins of each cable upon the other side of the diaphragm. This compartment is then closed by a similar lid to that used upon the cable side. In order to make tests or effect crosses the cable side of the box need not be interfered with, since the short lengths of insulated wire upon the other, or cross-connection side of the diaphragm may be manipulated as required. A ¾" gas plug is added, so that a desiccator may be connected or an escape provided when it is only necessary to pump through one cable from a distant point. A cable connection box of similar design is employed where it is desired to fix the box to a wall.

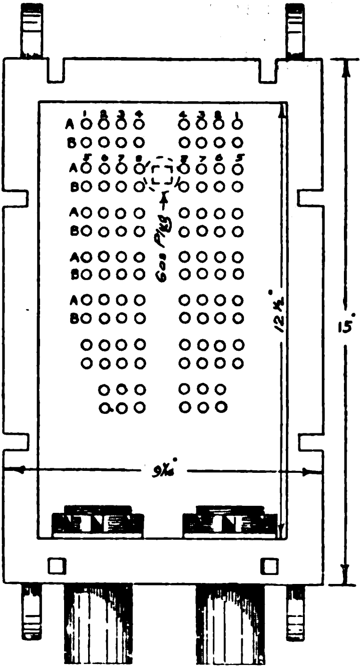

FIG. 597.—Back view of cable connection box with lid removed.

It may now be explained that the wires in an ordinary twin, quadruple pair, or multiple pair air-space cable are numbered in pairs, and that the two wires of each pair are distinguished as the *A* and *B* lines—a convention which owes its origin to telephonic requirements. The wires of screened single-conductor cables are, however, numbered individually.

CABLE DISTRIBUTION HEADS.

In the London telephone system the wires from the main cables are passed through cable distribution heads, and from these points the wires to the subscribers' premises are taken out in 7-pair cables. The number of wires to be taken out at each cable head is, of course, carefully considered when the jointing is to be performed, but should more wires be needed at this point or should too many have been allowed matters may readily be adjusted by opening the cable head.

CABLE DISTRIBUTION PLUGS.

The method of dealing with long lengths of cable connecting two large offices has now been dealt with, but there remains the arrangements required for joining an underground to an open route, and also the method to be adopted where it is required to serve sub-offices *en route*.

Taking the first requirement, it will be obvious that in connecting underground to open wires the conditions to be met are (1) to preserve the air-tight condition and to maintain the high insulation of the cable, (2) to provide protection from lightning, and (3) to provide a testing point. A lead sleeve of the general shape indicated in Fig. 598 is passed over the cable, and its conductors are then jointed to those of the two wire lead-covered cables upon one side of the plug. These two wire cables have enamelled conductors and are each served with cotton. The enamel on the plug conductors is removed with emery paper and the joints insulated with paper sleeves which have previously been impregnated with paraffin wax. The plug consists of the requisite number of two-wire enamelled and cotton-covered lead cables, each of which is rendered air-tight with insulating compound around which a circular plug of lead is cast. Upon completion of the jointing the sleeve is slipped over and the larger end soldered to the plug, whilst the cable end is soldered or wiped to the cable in the ordinary way.

Where a pole test box is not employed the twin cables (colloquially termed "tail-ends") are neatly cleated to the arms on their way to the pot-head insulators. The plugs have 40-lb. conductors when used for terminating telegraph, trunk, or junction cables, and 10-lb. conductors for cables carrying only subscribers' circuits. The tails are from 6′ to 10′ in length, and are thus long enough to reach the insulators.

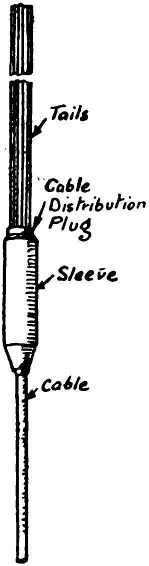

FIG. 598.—Cable distribution plug.

PARALLEL JOINTS.

In order to provide access to the wires within an underground cable a parallel joint is used.

In this way the wires required to be led off from the cable may be joined to a small cable, and brought out as indicated in Fig. 599.

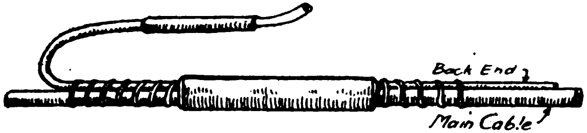

FIG. 599.—Parallel joint

The back ends can either be brought out as shown, or insulated and left inside the joint. The method of jointing the wires is the same as in making a through joint, but the sleeve enclosing the joint has to be a split sleeve, and care is required in seaming the joint with solder.

RENEWAL OF DRY CORE CABLES.

Where a spare conduit exists the new cable is first drawn in; the wires are then numbered and labelled at each end, and the old cable gradually cut out pair by pair. If there is but a single conduit the circuits in the cable may be diverted through a temporary aerial cable slung on tram standards, lamp standards, or short scaffold poles standing in casks. In the case of telephone subscribers' cables containing a large number of wires this course is impracticable, and arrangements are made to withdraw the old, and draw in the new, cable and joint it during the week end.

SURVEYING.

As regards surveying for a new underground route, but little which is not fairly obvious can be said. The type of paving is, of course, a vital factor in the cost of the work, and where it is possible to make a choice the cheaper proposal is selected. The obstructions likely to be met with may be ascertained by observation and by direct inquiry. In the first category come projecting cellars, electric light mains (from the position of the boxes), etc. Inquiries made from the Electricity Supply authorities, from the Gas and Water companies, usually suffice for estimation of the obstructions.

Where the choice of routes lies between busy and comparatively unfrequented thoroughfares, the latter are chosen on account of the superior facilities which they offer for the execution of the work and its subsequent maintenance. At the same time, tortuous routes and frequent road crossings should be avoided, but there is little in these considerations which is not of a very obvious character.

The pipes should where possible be laid in straight lines between consecutive boxes in preference to following the lines of the kerb. Electric light mains should be given as wide a berth as possible in order to minimize the chances of faults leading to the formation of an arc with the Department's pipes.

As in the construction of aerial lines, so with underground work can economy be effected by carefully considering the laying out of the stores and general organization of the work.

FAULTS.

A total disconnection in a cable may be localized by measuring the capacity of the wire from each end of the cable, whereas a partial disconnection or a defective joint has to be located by opening the various joints *en route*.

The positions of an earth or contact fault may be localized as described on pages 746 to 751.

The breakdown of the whole route, due to the entrance of moisture, is usually due to a defective wiped joint, but with the dry-air test which is now employed, this occurrence is comparatively rare. When the wires upon the outer layer are periodically tested, there is frequently ample warning that a defect exists, and, by applying the dry-air plant its position may readily be located.

It is sometimes necessary to cut out a short length of saturated cable and substitute a new piece, but the method of accomplishing this is so obvious as to need no comment.

POLE TEST BOXES.

It is often necessary to provide testing facilities, *i.e.* facilities for looping, crossing, disconnecting, or earthing the wires, at points which are remote from any office where an ordinary test box can be provided. At the junction between an open and underground line, pole test boxes are provided, but in this case they also serve to carry the fuses and lightning protectors needed to ensure the safety of the covered wires.

When testing facilities only are needed a simpler form of pole test box is used, but when protectors are also required the "G" type is fitted.*

In some cases, an ordinary test box is fixed in a hut placed at the foot of a pole. Where the junction or testing point is of less importance fuse insulators are fixed on the pole, but short lengths of copper tubing are used instead of fuses.

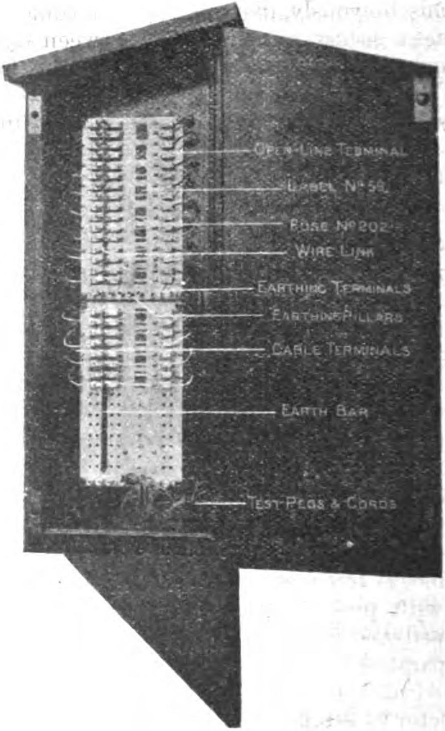

Fig. 600.—Pole test box. G type.

The box is of teak, varnished inside and painted outside.

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* "A New Pole Test Box." *P. O. E. E. Journal*, Vol. IV. p. 15.

The doors are hinged and bed against rubber cushions fixed round the edges of the box. Each door is closed by screws, so shaped that they cannot be removed from the door, and a special forked screwdriver is provided for turning them. This device renders it extremely unlikely that any mischievously disposed person could open the box, provides a secure and tight fit between the lids and the box, and precludes the possibility of the loss of the screws. The boxes are made in six sizes to accommodate 16 to 96 wires, that illustrated in Fig. 600 being a two-panel box for 32 wires. Fig. 601 illustrates the method of insulating the wires by ebonite blocks, the earth bar, spark gaps, the wire link and the glass tube fuse. The blocks A and B fixed at each side of the earth bar are furnished with projecting tinned brass pieces which are wedge-shaped and knife-edged. The edges are polished and are separated by $\frac{1}{64}$ inch from the earth bar, which is also polished at the sparking gaps, thus forming a lightning protector of simple form. The tubular test pillars are normally connected by a removable wire link. Six brass earthing pillars and three crown cup earthing terminals are provided at the bottom of each panel; the former are for connecting wires to earth by means of test plugs and cords, and the latter for earthing an open wire direct, *i.e.* eliminating the fuse. Each 16-wire panel is also provided with a separate sheet-iron cover which completely covers the testing side of the panel. On the

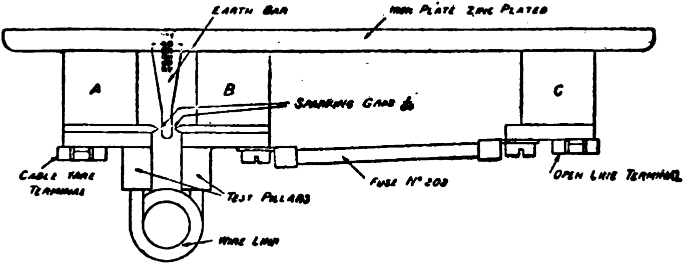

FIG. 601.—Plan of insulating blocks, wire link and fuse.

other side of the box provision has been made for the use of two-wire lead-covered cables on the open side. An extra length of 5 feet of cable is allowed from which the lead covering is stripped, the sheathing being securely sealed with Chatterton's compound. The flexible wires are then given a few turns round a bobbin (to introduce the requisite inductance) before being taken to the cup hook and thence to the open line terminal. Thus the open wire passes through an inductance coil, fuse, and a wire link with a lightning protector interpolated, before connection to the underground.

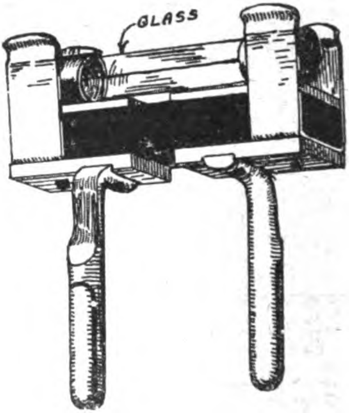

FIG. 602.—Fuse U-link.

Here it may be well to state that in older types of pole test box U-links and test holes of the ordinary pattern were used, and "C" or vacuum protectors fitted, the latter being used where dampness rendered the former unsatisfactory. When fuses were required the U-links were replaced by fuse U-links (Fig. 602).

The arrangements at the junction of an underground and an open route are conventionally indicated in Fig. 603. The underground route commences at the underground chamber and terminates in a cable distribution plug fixed on the terminal pole. From this plug lead-covered tails are jointed to $\frac{2}{40}$ I.R.V. (indiarubber vulcanized) core cables for connection to the test box terminals. The pot-head insulators are similarly connected to the open line terminals of the test box.

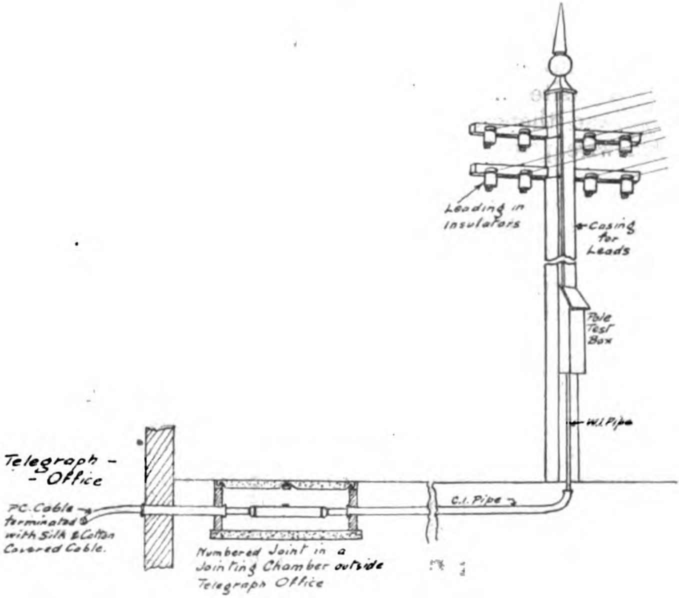
Leading in Insulators
Casing for Leads
Pole Test Box
W.I. Pipe
Telegraph - - Office
PC. Cable terminated with Silk & Cotton Covered Cable.
C.I. Pipe
Numbered Joint in a Jointing Chamber outside Telegraph Office

FIG. 603.—General view of the arrangements necessary for connecting an underground cable to an open line

APPENDIX A.

THE MOLECULAR THEORY OF MAGNETISM.

THE well-known experimental fact that a magnet may be broken into any number of pieces and yet each piece still be found to be a perfect magnet early suggested that magnetic properties were of molecular* origin. From this point commenced the evolution of molecular theory of magnetism which has reached its present development by the labours of Prof. Ewing. This theory, which so closely and accurately fits the known facts of magnetism, states that every molecule of a magnetic substance is always a magnet, perfect and complete in itself, and that magnetization is due to the molecular magnets being more or less completely faced round, in opposition to their mutual attractions, so that they tend to act in the same direction. In the unmagnetized condition the molecules are in positions in which their mutual attractions are satisfied. Consideration will show that when this is the case the total effect of the collection of molecular magnets will be *nil*, since half the North poles will be pointing in one direction whilst the rest are acting in the opposite direction. The intensity of the magnetization has a definite limit known as the point of saturation, and as it is desirable that a clear conception of the physical meaning of the state should be realized, a simple illustration of the two conditions of a piece of unmagnetized iron and of the same saturated will be shown here—

N | NS — NS — NS — NS — NS — NS | S
  | NS — NS — NS — NS — NS — NS |

FIG. 604.—Arrangement of molecules in a magnet.

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* For definition of molecule, etc., see p. 919.

Each pair of small letters *NS* represents a molecule of a magnetic substance. Twelve molecules only have been shown, whereas the smallest magnet used in practice consists of billions. The twelve molecules all face in the same direction, viz. with their North poles to the left, and the effect of their combined action is to produce North polarity on the left and South on the right as indicated by the pair of large letters *N* and *S*. Since the magnets are all acting in exactly the same direction it will be obvious that the effect produced will be the maximum possible, and this condition is termed saturation.

The unmagnetized condition of the iron may be represented thus—

$$\left(\begin{array}{c} \mathrm{NS - NS - NS - NS - NS - NS} \\ \mathrm{SN - SN - SN - SN - SN - SN} \end{array}\right)$$

Fig. 605.—Arrangement of molecules in a piece of unmagnetized iron.

Here it will be noticed that half the magnets point one way whilst the remainder act in the opposite direction, and the net result is therefore *nil*. It is most important to note that in this condition the attraction of each magnet is satisfied by that of its neighbour. The lower six magnets have turned through 180° from their positions in Fig. 604.

It is important to realize that the prime cause of this rotation is the satisfaction of the mutual attractions of the molecular magnets. Imagine, therefore, that the magnetizing force is withdrawn from the piece of iron shown in Fig. 604. The molecules are perfectly free to turn round, but their distances from each other are fixed. If the upper and lower molecules on the left were absolutely parallel the repulsion of the two Norths would balance that between the two Souths, and their positions would remain unchanged. This balance would probably be far finer than that necessary to balance a billiard ball upon the point of a needle. In other words the position would be an unstable one, liable to be upset by the most minute vibration. The result would therefore be that the attraction between the poles of opposite sign would produce a rotation of one of the molecules. This will be rendered more obvious by considering the distance between the molecular magnets greater than their length.

In the case of steel the molecules appear to be in some way jammed, and are very difficult to turn round, but when this has been done the mutual attractions are not strong enough to produce de-magnetization. When, therefore, a piece of steel is magnetized it remains magnetic after the removal of the magnetizing force, and is then termed a permanent magnet in contradistinction to iron, which, on account of its molecular inter-attractions, returns to the non-magnetic condition immediately the magnetizing force is withdrawn.

Having considered the two extreme states of non-magnetization and saturation it is now desirable to investigate the conditions which lie between them. In an actual magnet it is highly improbable that the arrangements of the molecules are of the remarkably simple character shown in Figs. 604 and 605. The molecules are arranged in groups of varying number and complex chains, and groups which are, from a magnetic point of view, self-contained, exist in such a manner that the attractions of each member of a group or chain are satisfied by those of the others.

If a very small directive magnetic field is applied to the piece of unmagnetized iron the various molecules are slightly deflected from the positions which they occupy. This small deflection of the various members of the groups disturbs the balance of poles, and a magnetic effect due to the iron is observable. By increasing the value of the directive field the molecular deflections increase, thus definitely increasing the magnetic effect due to the iron. At this stage the magnetic effect due to the iron itself is very roughly proportional to the value of the directive field. A point is, however, soon reached where a small increase in the value of the directive field produces very large increases in the magnetic effect due to the iron. At this point the deflections have become so great that the chains and groups become unstable and finally break up altogether. The great changes which ensue naturally entail a largely increased magnetic moment. These changes increase in magnitude with the increase of the magnetic field applied until a point is reached where the molecules have reached a stable position. Further increases of directive force now produce smaller and smaller increases of moment until a point is reached where no appreciable increase of moment can be obtained. This is the point of saturation, and corresponds to the extreme condition shown in Fig. 604.

Since, however, the position which the molecules take up is the resultant of two opposing forces, viz. the directive force and the inter-attractions of the various members of the numerous groups, the molecules can never all of them wholly act in the same direction as directive force.

The magnetization of a piece of iron may be divided into three definite stages. There is the first stage in which the molecules retain their groupings, but each member is deflected. In the second stage the deflections are greatly increased, and the groups and chains are unstable. In the third stage the increases in moment are due to increased deflections of the molecules.

During the first stage of the magnetization the removal of the directive force will at once enable the molecules to resume precisely their original positions. This demonstrates the experimental fact that iron which has been but weakly magnetized exhibits little or no residual magnetism. Turning now to the second stage, where the groupings are unstable and where large changes have occurred, it is not surprising to find that the withdrawal of the magnetizing force does not cause each molecule to resume exactly its former position. New groupings are formed and the molecules satisfy each other's attractions in the most unsymmetrical fashion. The result is that there is left a distinct magnetic moment due to the molecules. The residual magnetism observed is thus accounted for. That which has been said of the second applies equally to the third stage, and it is a well-known experimental fact that considerable residual magnetism is observed when the magnetizing force is withdrawn.

The results obtained from the above consideration clearly show that the amount of magnetism which a piece of iron manifests depends upon the value of the magnetizing force. At first the effect increases comparatively slowly to a certain point where small changes in magnetizing force produce large changes in the resulting magnetization. Finally the point of saturation appears. In the first stage there is little residual magnetism in comparison with the second and third stages.

It should be stated that Ewing's theory was based upon the observation of the behaviour of a flock of freely pivoted compass needles placed close together with a large circular coil of wire at either end of the group. The current through these coils could be varied to any required extent and a directive magnetic field of any particular value caused to act upon the group of needles. Their behaviour entirely corresponds with the statements made in the description of the behaviour of the molecules of iron. Indeed, the quantitative values of magnetic effect due to the needles themselves show a remarkable correspondence with the value obtained in practice from a piece of iron. The theory is supported by innumerable facts, and its accuracy can scarcely be questioned.

APPENDIX B.

NOTES ON CHEMISTRY.

A LUMP of sugar may be pounded with a hammer until the particles are very small, and by using a mortar and pestle their size can be still further reduced. If, however, these particles are examined by means of a microscope, or even by an ordinary lens, it will be found that the particles have still some size, and evidently could be made yet smaller. If the sugar is dissolved in some warm water the particles will become so small as to be invisible, but we know by the taste that the sugar is there. We may dilute it largely and still recognize the sugar, which is evidently distributed equally throughout the liquid. The question now arises as to whether the sugar is capable of unlimited division. Experiments prove that it is not, but that ultimately a particle which will no longer split up and yet remain sugar will be arrived at.

This is called a *molecule*, and is the smallest particle which can exist free. Sugar is known to consist of carbon and the elements of water, *i.e.* hydrogen and oxygen, and if a little strong sulphuric acid be added to the sugar solution the acid will combine with the water, black carbon will be liberated, and the vessel will become very hot. If the sugar is dissolved in some warm water in a tall glass, and the strong sulphuric acid poured slowly in, the carbon will rise and flow out of the glass in a remarkable manner. It may be remarked in passing that this heat is caused by the chemical action, and is always given off during chemical union. Now it is clear that the molecule has separated into still smaller particles of substances quite distinct from sugar. These particles are called *atoms*, and every molecule is so built up. The carbon produced has not yet been decomposed, and is therefore called an *element*. It is evident that compounds are made up of elements, but it is also as certain that elementary atoms do not exist alone but in groups or molecules, generally of two atoms, but in one or two cases of one, two, three, four or even six atoms. An *atom* may therefore be defined as the smallest particle of matter that can enter into combination. An atom of hydrogen is represented by H, but in the free state as a molecule as H_2. An atom of oxygen is represented by O, a molecule by O_2, and a molecule of ozone by O_3, showing that in this gas three atoms are condensed into the same space as two of ordinary oxygen.

In order to avoid writing the names of each of the elements composing a compound a system of chemical symbols is used, thus: Hydrogen is represented by H; Sulphur, S; Copper, Cu; Carbon, C; Oxygen, O; Manganese, Mn; Zinc, Zn; Mercury, Hg; Chlorine, Cl; Potassium, K; Chromium, Cr; Nitrogen, N; Lead, Pb; Sodium, Na.

A number placed after a symbol indicates the number of atoms which is to be considered. For instance, a molecule of sulphuric acid consists of two atoms of hydrogen, one of sulphur, and four of oxygen. In order to write this quickly each element has been given a distinctive symbol, and to indicate the number of atoms in each element in the compound a figure stating the number is placed after each element. Where, however, there is only one atom the figure "1" is understood and is not written. Sulphuric acid is therefore H_2SO_4. In order to express more than one molecule of a substance a large figure is placed before the compound thus:—$2NH_4Cl$. This means two molecules of NH_4Cl, or two atoms of nitrogen, eight of hydrogen, and two of chlorine. $2H_2$ means two molecules of hydrogen, each of which consists of two atoms, *i.e.* four in all. $4Cr_2(SO_4)_3$ is the symbol for four molecules of chromium sulphate, each of which consists of two atoms of chromium, three of sulphur and twelve of oxygen.

Chemical compounds are known by the thousand, but there are also groups of elements which have no independent existence, but which can take part in chemical reactions and be transferred from one compound to another. These groups are called *radicles.* An atom of hydrogen H or oxygen O are elementary radicles. SO_4, NO_3, HO are compound radicles. Radicles are also divided into metallic as Na, Zn, NH_4 and acid as Cl, SO_4, NO_3.

It is evident that they exist free for a very short interval, in chemical reaction, before they re-unite to form fresh molecules. In this condition they are said to be *nascent*, and their chemical activity is very great.

Compounds are formed by the union of these radicles in almost every conceivable way, but the great majority belong to the three following groups:—

1. *Acids* which are extremely active chemical compounds and are formed by the union of hydrogen, H, with an acid radicle, as:—

   H_2SO_4 Sulphuric Acid.
   HNO_3 Nitric Acid,
   HCl Hydrochloric Acid.

2. *Bases.* Hydrates or hydroxides are formed by the union of the radicle hydroxyl HO with a metallic radicle, as:—

   Potassium hydrate KHO.
   Ammonium hydrate NH_4HO.

3. *Salts* are formed by the union of a metallic and an acid radicle:—

   $Zn\,SO_4$ Zinc Sulphate.
   $NH_4\,Cl$ Ammonium Chloride.

The metals are often called positive elements and the non-metals negative, or still better a list of the elements can be made, the highest being the typical negative element oxygen, and at the bottom the typical positive element potassium. In this list each metal is negative to those below and positive to all above it. Also the further they are apart the more intense the chemical affinity.

The radicles may also be classified as positive and negative, thus SO_4 is negative because it is combined with the positive H, and the definition will become:—

> An *acid* formed of hydrogen and a negative radicle,
> A *base* formed of hydroxyl (HO) and a positive radicle, and
> A *salt* formed of a negative and a positive radicle.

Now to split up a compound requires energy, and when separated they possess potential energy. When the elements re-unite the energy is reproduced, and may exhibit itself in the form of heat, light, electricity, etc. Thus the sun for ages decomposed the carbonic acid gas in the coal forests, and with the carbon the plants were built up. This energy, after lying dormant for millions of years, is now utilized by us in the form of heat, really the original heat poured out by the sun ages ago.

Thus we see man can neither create nor destroy energy, and it is equally certain that he cannot create or destroy matter. All he can do is to change its distribution, and in so doing change its external appearance. Hence, in any chemical equation, every atom taking part in the reaction must be accounted for, *i. e.* if there are ten atoms on one side of the equation there must be ten on the other. The *quantities* of each element must be the *same*, but their *distribution* may be entirely different.

If a piece of pure zinc is placed in dilute acid, as for instance, sulphuric acid, no action takes place. If now, a piece of carbon, platinum or copper is also placed in the solution there is still no action. Lastly, if while they are in the liquids the elements are connected outside either by touching them together or joining them by a wire, the zinc immediately dissolves, while hydrogen gas is given off from the surface of the copper. At the same time the wire is very different to what it was in its normal state. It will deflect a magnetic needle as in the telegraph, make soft iron into a magnet, and produce other electrical phenomena according to the strength of the action. The energy of the chemical action exhibits itself as electricity, and a current of electricity is said to flow from the copper to the zinc outside, and from the zinc to copper inside, thus completing the circuit.

The copper plate is the positive pole and the zinc the negative, which can be remembered thus:—

CoPper Positive,
ZiNc Negative.

The vessel is called a cell, and a number of cells put together and joined up is called a battery. The action in the cell may be represented thus:—

Before the poles are connected. After connection.

Zn	+	H_2SO_4	=	$ZnSO_4$	+	H_2
One molecule of zinc	and	One molecule of sulphuric acid	form	One molecule of zinc sulphate	and	One molecule of hydrogen.

The copper plate is not acted upon by the chemical constituents of the cell, and is therefore omitted from the equation.

The reaction depicted by the above symbols represents a molecule of zinc acted on by a molecule of sulphuric acid, the result being that the zinc and the two atoms of hydrogen of the sulphuric acid change places, when we have zinc sulphate with hydrogen free instead of hydrogen sulphate (another name for sulphuric acid) and zinc free.

The solution of zinc sulphate at once leaves the zinc, and being heavier than water slowly sinks, so that fresh surfaces of zinc are continually being exposed to the action of the acid. The current will cease when all the zinc has been consumed, *i. e.* reduced to zinc sulphate. But in the case of the copper the hydrogen collects in a thin layer and clings to the surface. This is called polarization, and of course interferes seriously with the current. The remedy is to introduce another liquid which will unite with the hydrogen and remove it continuously. In the description of the various cells these are mentioned as they occur. In the instance used for illustration, that is, the two elements zinc and copper and sulphuric acid, the sulphuric acid is called the exciting fluid, and the liquid used to remove the hydrogen is called the depolarizing fluid, and may be a solution of copper sulphate forming sulphuric acid and metallic copper. The latter forms a layer on the original copper element and therefore the action is not impeded.

According to the most recent investigations, when sulphuric acid dissolves in water part of it at once separates into the radicles H_2 and SO_4, or *ions*,* as they were first termed by Faraday. These are in equilibrium with themselves and the copper and zinc, but directly the connection is made there is a means of escape for the energy, the zinc attracts the SO_4 and the hydrogen goes to copper. A fresh portion of H_2SO_4 decomposes into ions, and so the action goes on continuously.

Similarly when sodium chloride, NaCl, is dissolved in water it will immediately split up into the *ions* Na and Cl. Now, if a current of electricity is sent through this solution the Na is attracted by one pole and is set free, forming NaHO with the water, and the Cl is attracted by the other and escapes as gas. Some more NaCl decomposes, and the action goes on until all the salt is decomposed.

Substances like sugar ($C_{12}H_{22}O_{11}$), with a very large number of atoms, are not decomposed by electrolysis and consequently do not split up into *ions*.

What has been said about the atom is based on Dalton's Atomic Theory, which assumes that the atom is the ultimate form of matter, and is indivisible and indestructible. It must, however, be mentioned that the researches of the last few years, especially the discovery of Radium, have led to the conclusion that the atom itself is composed of thousands of still smaller particles in rapid motion. These have been called *electrons*. Also that the new element Radium, with an atomic weight of 250, is capable of breaking up into Helium, whose atomic weight is 2.

Another example of a chemical equation is given. It indicates the chemical action of a Leclanché cell with manganese chloride as excitant:—

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* Strictly speaking, H is an ion, but not H_2.

Before the poles are connected.				After connection.		
Zn	$+$	$MnCl_2$	$=$	$ZnCl_2$	$+$	Mn
One atom of zinc	and	One molecule of manganese chloride	form	One molecule of zinc chloride	and	One atom of manganese.

Mn	$+$	$3\ MnO_2$	$=$	$2\ Mn_2O_3$
One atom of manganese	and	Three molecules of manganese dioxide	form	Two molecules of manganese sesquioxide.

It will be observed that no gas is liberated as the result of this action and that manganese is the polarizing ion.

ADDITIONAL DEFINITIONS.

An *electrolyte* is a liquid which undergoes *electrolysis*, *i.e.* chemical changes, when traversed by a current.

The *electrodes* are the conductors in contact with an electrolyte by means of which the current enters and leaves the liquid.

The *anode* is the electrode by which the current enters the electrolyte and the *kathode* that by which it leaves. This definition is best memorized by the aid of the following mnemonic :—" When *Ann* comes *in*, the *cat* goes *out*."

The *anion* and *kation* are the elements (or groups of elements) liberated at the anode and kathode respectively.

In the simple voltaic cell considered, zinc is the anode, copper the kathode, and hydrogen the kation.

APPENDIX C.*

THE GULSTAD RELAY.

THE Gulstad relay is essentially of similar design to the P.O. standard relay without differentially wound line coils. By means of an adjusting screw the electromagnets can be closed in, or opened out, thus varying the air gaps between the pole pieces and the armatures. Also, it is furnished with two additional windings which are used to keep the tongue of the relay vibrating between the contact points at a constant speed adjusted to be equal to the speed of the reversals of the distant transmitter. The function of the line current passing through the main windings is merely to arrest or suppress the vibration of the tongue maintaining it on S or M according to its direction. In this way the work of moving the tongue from side to side is performed by the auxiliary windings and local battery. One reason for the lack of sensitiveness in an ordinary relay is the magnetic attraction between the armature and the nearer pole piece of the electromagnet; so that although a current may cease and even be changed in direction, some little time will elapse before the reversed current will have risen sufficiently in value to cause the armature to move towards the opposite and more distant pole piece of the electromagnet. This defect is nullified by the vibrating tongue and results in a sensitiveness several times greater than that of the ordinary P.O. standard relay. It has been found to be possible to work circuits having a KR as high as ·75 second, with the vibrating relay. A speed of 200 words per minute has been obtained with a current of only ½ m.a. in the line coils.

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* The Author is indebted to Messrs. A. H. Roberts, M.B.E. and J. L. Taylor for much of the information contained in this Appendix, and for checking the section.

The Gulstad Relay by E. Lack, *P.O.E.E. Journal*, Vol. VII, p. 163, *Ibid.* The standard G relay by A. H. Roberts, M.B.E., Vol. XIII, p. 21–23.

Additional or auxiliary windings have been added to the P.O. standard relay, so as to employ the Gulstad principle, and it is then officially designated a "*G*" relay. The resistance of the main windings is 100^{ω} + 100^{ω} and that of the auxiliary or local coils also $100^{\omega} + 100^{\omega}$.

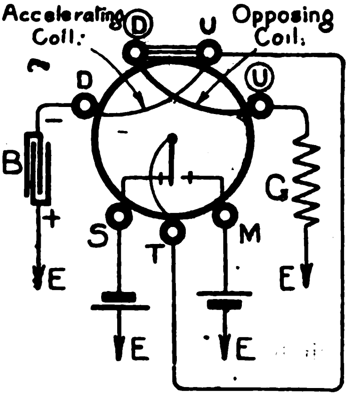

FIG. 606.—Principle of Method of Vibrating the Tongue of the Relay.

The vibrating relay increases the working margin on long distance fast speed Wheatstone circuits, and on some of the lengthy underground and submarine cables the average rate of transmission is improved by 50 per cent. By fitting *G* relays on the London-Newcastle quadruple duplex Baudot, the repeater formerly required at Warrington was dispensed with and direct working established. The length of the circuit is 358 miles, and its KR 103,700. In several cases bridge duplexes have been converted to differential duplexes—not the least of the advantages of which is that the duplex balance is rendered easier of day to day adjustment. When the steady current in the line circuit is kept below 10 m.a. there is a tendency to register false signals by vibration of the instrument table, but this has been prevented in such cases by supporting the relay on spring trays similar to those used on Baudot sets.

The *principle* of the method by which the tongue

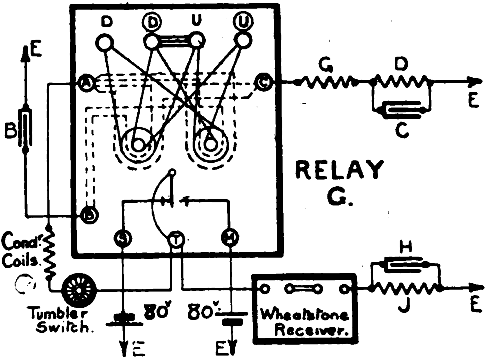

FIG. 607.—*G* Relay.

is, when uncontrolled by the line coils, kept in a constant state of vibration between S and M is illustrated in Fig. 606. Positive and negative voltages are connected to M and S, T is joined to the split of an ordinary standard relay adjusted to neutrality, D and U-circle being connected respectively to an adjustable earthed condenser and a set of resistance coils. Imagine that the tongue, moving over from M to S has just reached S. The negative voltage is thereby applied to the split of the relay and there is instantly a short heavy rush of current through the plain coil in the spacing direction to charge the condenser in the direction shown.

At the same time an opposing current commences to flow in the marking direction through the circle coil of the relay. But, the short heavy rush overpowers the steady current thus, while it lasts, increasing the pressure or impact of the tongue on S. Immediately it has died down the steady marking pull of the opposing current through the circle coil asserts itself, and the tongue commences to move towards M. The moment T breaks contact with S the condenser discharges in the marking direction through both windings of the relay in series with the resistance G thus accelerating the motion of the tongue towards M. When the tongue reaches M the positive voltage is applied to the split of the relay and the short heavy

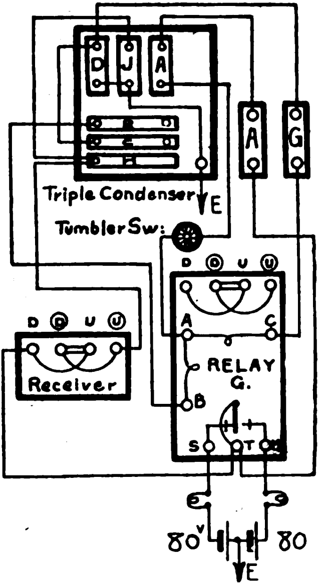

FIG. 607A.—Actual Connections of *G* Relay.

rush of current charging the condenser in the reverse direction momentarily preponderates over the current through the circle coil of the relay, thus increasing the firmness of the contact between T and M. The steady spacing current through the resistance G takes charge as soon as the rush of current to charge the condenser is over and the tongue is urged towards S; on T breaking contact with S the condenser current through both coils in series accelerates the motion of the tongue to S. This process is repeated successively and the tongue vibrates between S and M at a rate depending on the voltage used, and the values of the capacity of the condenser and of the resistance.

The "*G*" relay consists of a P.O. standard relay having in addition to its ordinary coils D, U, and D-circle, U-circle an extra differential winding on its electromagnets arranged in accordance with Fig. 606, and connected to three terminals A, B and C, as shown diagrammatically in Fig. 607. The rate of vibration is made equal to that of the reversals of the distant transmitter, and on very long circuits it is important that the rate at which the local currents rise in the auxiliary windings should correspond as closely as possible with the received cable currents. When these conditions have been secured, the cable current effect being slightly greater than the local current effects, the vibration of the relay is controlled by suppression of vibrations, and the tongue is surrendered to local forces. When the line current falls below the value of the local current in the opposing coil the relay tongue is set in motion, and it is this anticipatory effect which is so valuable. On very long lines it is only the dashes which have any real controlling effect, the dots being of such a small current value that the relay interpolates them automatically.

The function of the condenser is (i) to hold the tongue momentarily against whichever contact it may be placed, (ii) to accelerate the transit of the tongue between the contacts and (iii) to give firm reliable contacts due to the vigorous impact of the tongue on the contact points thus breaking down any film of oxide and assuring definite contact more rapidly than if the tongue were controlled by the relatively feeble line currents. The transient holding effect also ensures quick establishment of definite contact by preventing the rebounding of the tongue at the moment of impact with the contact. One other advantage of the Gulstad principle is that the local accelerating and opposing coils take charge of the movement of the tongue of the relay during the zero interval, *i.e.*, during the period of time when the line current is changing in direction and the tongue of the relay is necessarily surrendered to any induced or leakage currents from other circuits which may be present. In practice, it is usually the case that an amount of current equal to about one m.a. rapidly changing in direction is usually present. This may be observed by setting the relay neutral on any long circuit, and noting the resulting chattering of the sounder when the relay is joined to line. The *G* relay effectually obviates this, and there is, therefore, no necessity for the definite spacing bias always used in practice on double current circuits.

The details of the practical arrangement of the *G* relay are shown in Fig. 607A. The two condenser coils in series AA determine the rate of charging of the accelerating coil condenser B. The opposing coil resistance in Fig. 606 is replaced by a set of condenser coils G and a shunted condenser consisting of condenser coil D and a condenser C. The Wheatstone receiver worked in the local circuit from T has a shunted condenser consisting of a fixed resistance J and a condenser H, the function of which is to balance the inductance of the receiver. The manner in which these resistances and capacities are arranged is shown in Fig. 607A, lettered to correspond with Fig. 607. The terminals D, D-circle, U and U-circle of the *G* relay are joined up in place of the standard relay or Wheatstone receiver according to the type of circuit in question. For a quadruplex circuit, the Wheatstone receiver in the local circuit would, of course, be replaced by a standard relay. In the case of a bridge duplex circuit the *G* relay would take the place of the Wheatstone receiver, but the shunted reading condenser would be retained in series with the line coils of the *G* relay.

The determination of the best values of resistance and capacity on a new circuit requires a certain amount of experiment, but the values once found remain fairly stable, and the day to day variations are small and are quite readily effected. If the local control is stronger than the line current the dashes will be split and the slip will in extreme cases show dots only. If the rate of vibration is higher than the rate of the incoming reversals the relay will tend to operate too much in advance of the transmitter, and either the signals or the spaces between the signals will be clipped depending upon the slight bias prevailing, it being impossible in practice to secure an absolutely neutral adjustment of the relay. If the rate of vibration is too slow the relay will not anticipate the action of the distant transmitter, and although it will still work with reduced transit time and with definiteness of contact, the working speed will have to be reduced if this is approaching the speed limit of the circuit.

Before switching the *G* relay on to the line it should be set to vibrate at about the right speed. This may be ascertained by noting the length of slip run out in a given time, and counting the number of dots recorded. When the relay is joined to line, a test slip consisting of groups of 12 dots 12 dashes and words such as "to-morrow" and "selective" should be passed through the distant transmitter. The resistance A should be decreased until the dashes split and then gradually increased until the dashes are restored. If the signals are clipped the capacity in B and the resistance in A should be increased, while if the dashes run together with the dots good or the dots too small but the dashes right, the resistance in G should be increased, while that in A and the capacity of C should be decreased.

On a bridge duplex circuit a reading condenser is provided in series with the line coils of the *G* relay, and correct adjustment may be obtained by reducing the capacity if the signals tend to break up into dots of irregular size or by increasing it if the signals tend to run together.

The correct adjustment of the speed of vibration may be verified by superimposing two slips taken at the same receiver speed, one with the line controlling the relay, and the other with the line removed from the relay. The dots recorded when the relay is uncontrolled should be somewhat longer and slightly further apart than with the line connected. This indicates that the vibration of the relay is slightly slower than the distant transmitter (a condition rendered necessary owing to the impossibility to secure absolutely neutral adjustment of the relay), and if left to itself the relay would alternately get into and out of step with the transmitter reversals. Immediately the line current is switched on to the relay, this want of synchronism is corrected as the relay is rapidly pulled into step and so maintained.

The day to day adjustments which may be necessary are best made by fixing A on a current value basis which should be slightly less than the line current, and then to alter the rate of vibration by varying B, C, and D.

To increase the rate, reduce A, B, D, or G, or increase C.
To reduce the rate, increase A, B, D, or G, or reduce C.

If the condensers are correctly adjusted, the reversals should be regularly spaced when the speed of vibration is slightly varied by increasing or decreasing A.

The values of the various quantities are given as an example below :—

Res. or Capacity	$GW.BE_1$ (quadruplex)	$GW\text{-}DN_1$ (differential duplex)	$GW\text{-}BM_1$ (Bridge duplex)
A	2,350 ω.	500 ω.	2,000 ω.
D	700 ω.	700 ω.	3,000 ω.
G	300 ω.	50 ω.	200 ω.
J	1,000 ω.	6,000 ω.	6,000 ω.
B	7 mf.	7 mf.	5 mf.
C	3 mf.	3·75 mf.	7·5 mf.
H	·5 mf.	1·5 mf.	1·5 mf.
E	——	——	7·5 mf.
F	——	——	8,000 ω.

The coil G is only required on P.O. lines in exceptional circumstances, usually where a moderately slow speed is required, which could not otherwise be satisfactorily obtained. A slight increase in the resistance G has a marked effect in slowing the speed of vibration.

When the *G* relay is used on a repeater on long cables it may be necessary to provide a transmitting relay if the sparking at the contact points, due to line discharges, should seriously interfere with the regular vibration of the relay when the tongue of the *G* relay is connected directly to line instead of operating the transmitting relay. In P.O. practice this provision has not, so far, been necessary.

Residual magnetism in the cores of the electro-magnet is fatal to the good working of the instrument, the highest quality of soft iron is therefore used, and is tested after winding for magnetic balance. A minor improvement in detail consists in protecting the connection from the coils to the terminal plate by a short length of flexible insulating tube near the plate to prevent possibility of the connections being damaged by the edge of the permanent magnet.

APPENDIX D.

SUPERPOSING.

THERE are several systems by which a telephone circuit may be used for simultaneous telegraph and telephone work. The van Rysselberghe system, which enables two telegraph circuits to be obtained from a metallic telephone circuit, is shown in Fig. 608, the telegraph apparatus at F and G being arranged precisely as that at C and D.

The principle of the system consists in slowing down the rate at which the telegraph currents rise and fall to such an extent that no audible effect is produced upon the telephone receivers, whilst the telephone speaking currents are, of course, so small as to be quite incapable of affecting the telegraph apparatus. In order to separate the two telegraph circuits, four condensers, each ½ m.f. capacity, are inserted in the lines. Since the telephonic speaking currents are of a rapidly alternating character, the interposition of these condensers does not appreciably affect the talking between the telephones at A and B. An inductive resistance termed a "graduator" (Fig. 608) is inserted between the centre of the key and the line, whilst a second and similar coil is joined between the battery and front stop of the key, a 2 m.f. condenser being connected between the centre of the key and earth. When the key is depressed the battery commences to charge the condenser and the difference of potential between the centre of the key and earth rises slowly, while the graduator in the line circuit tends still further to reduce the rate at which the current increases. The current therefore rises very slowly, and the portion which passes through the nearer condenser, telephone A, condenser and telegraph apparatus F upon the other line, whilst the current is rising is far too small to affect the telegraph apparatus, and since it rises so slowly the telephone is likewise unaffected. Consideration therefore shows that the two telegraph circuits may be worked simultaneously upon the metallic loop without interference with telephonic speech or with each other.

The only point to be remarked is that, for calling purposes upon the telephone circuit, it is necessary to adopt a special device which will not affect the telegraph circuits as would the use of an ordinary generator. This is accomplished by the low frequency current from a small induction coil acting upon an extremely sensitive form of relay at the distant end.*

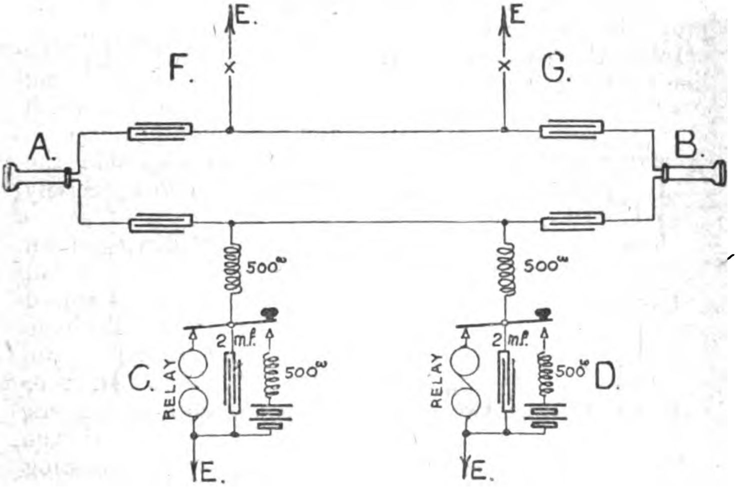

Fig. 608.—Van Rysselberghe system of simultaneous telegraph and telephone working; the apparatus at *F* and *G* is precisely similar to that at *C* and *D*.

Successful results have been obtained in this country over circuits of roughly fifty miles in length with a modification of the arrangements of Fig. 608. The apparatus at C, D, F, and G consisted of double current duplex sets worked with polarized sounders, a 10 m.f. condenser being connected across each set. The inductance coils used in place of the 500ʷ graduator coils have a resistance of 40ʷ with very high inductance, and instead of the lines being taken through condensers to the telephone a toroidal repeating coil (*q. v.*), having a 2 m.f. condenser in the centre of its secondary coil, is interpolated, the primary being connected to the trunk switch section. It may be remarked that in order to improve the ringing, which is by ordinary generator ringing current, the condenser normally associated with trunk-line calling relay is short circuited.

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* See Chapter IV, "Telegraph Switching Systems," by T. F. Purves.

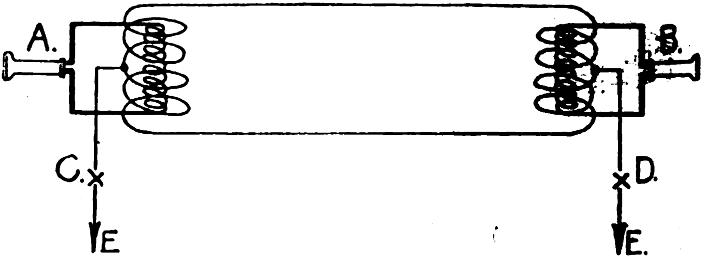

FIG. 609.—A telegraph superposed upon a telephone circuit with transformers.

The systems ordinarily used by the Post Office enable one telegraph to be worked over a metallic telephone circuit, but without in any way affecting the arrangement of the telegraph apparatus or the system of ringing over the telephone loop. If the circuit is in perfect condition there will be no effect upon the telephones when the telegraph stations are working. There are two methods of arranging for superposing, one with the aid of transformers and the other by means of bridging coils.

A telephone circuit, conventionally depicted in Fig. 609, has a telegraph circuit superposed upon it by means of transformers. The transformer (Fig. 610) is an induction coil of special design and has a closed magnetic circuit formed by fine iron wires.

The internal connections are shown in Fig. 611. The primary winding consists of two 75^{ω} windings, which are joined in series by connecting P and P_1 on one side. Before proceeding further it may be explained that the interpolation of a pair of these transformers reduces the speaking efficiency of the telephone circuit by an amount equivalent to adding from 10 to 12 miles of standard cable loop (20 lb. conductor paper core cable) to the circuit. This reduction in *speaking efficiency*, or "*transmission*," as it is termed, is of serious moment, and experiments have therefore been made with a view to improving the transmission without rendering it necessary to employ special ringing current. The toroidal repeating coil now adopted consists of an iron ring made up of a bundle of fine wires upon which are four equal 21^{ω} windings, thus giving a 42^{ω} primary and secondary. The interpolation of a pair of these coils is equivalent only to the addition of some two to three miles of standard cable. It is not as efficient for generator ringing as the seven-terminal transformer, but there is no difficulty in adjusting a relay to function reliably. The principle of action of the various types of repeating coil or transformer is identical.

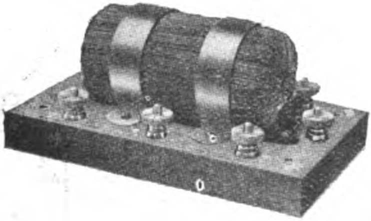

FIG. 610.—7-Terminal Transformer.

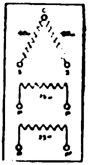

FIG. 611.—Internal connections.

The speaking currents from A (Fig. 609) pass through the primary winding and induce corresponding currents in the secondary, which in passing through the secondary at B induce currents in the primary, so actuating the telephone at B. The speaking in the reverse direction (*i.e.* B to A) is effected similarly. The central points of the two secondaries are connected to telegraph sets joined up in the ordinary manner. The telegraph currents from *C* divide equally through the two sides of the secondary, and as these two halves of the windings oppose each other the core of the transformer is not magnetized and therefore no E.M.F. is induced in the primary. The two halves of the total current pass along both lines in parallel, re-unite at the centre of the transformer at *B*, and pass through the apparatus at *D* to earth. It will therefore be seen that there is no interference between the telephone and telegraph circuits.

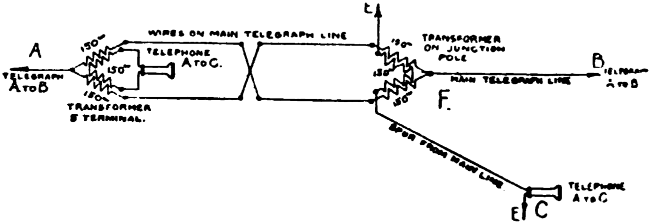

FIG. 612.—A single wire telephone circuit combined with a telegraph wire to form a metallic telephone circuit upon a main telegraph line.

The two lines must, however, be equal in conductor resistance, in insulation resistance, and in static capacity.

This system has been used to combine a single wire telephone circuit and a telegraph circuit upon a main line route so as to cut off the inductive disturbances upon the telephone circuit. In country districts, where there are neither electric tramways nor other telegraph and telephone circuits in the vicinity, a single wire circuit is quite adequate for the transmission of messages over a short distance.

An example of such a circuit is given in Fig. 612, where the *A*—*B* telegraph circuit allied with a section of the *A*—*C* single wire telephone circuit provides a metallic telephone circuit between *A* and *F* with the telegraph superposed upon it. There is therefore only the inductive disturbance and earth current effects between *C* and *F* upon the line, and in many cases this is quite of an insignificant character. It is, however, necessary to cross the two wires so as to eliminate inductive disturbances from the other circuits working upon the main line between *A* and *F*.

A telephone circuit upon which telegraph working is superposed by means of bridging coils is shown in Fig. 613.

This plan has the advantage that it avoids the interpolations of repeating coils, but it carries with it the disadvantage that when the telephone circuit is extended to another trunk the latter will, if unbalanced due to slight defects, cause the telegraph currents to affect the telephone receivers.

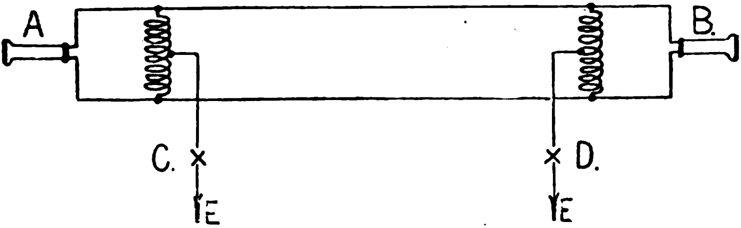

FIG. 613.—A telegraph superposed upon a telephone circuit with bridging coils.

The arrangement adopted for superposing a Hughes circuit upon the London-Paris trunk lines is illustrated in Fig. 614. It will be observed that a 10½ m.f. condenser has been placed across the terminals of the Hughes set in order to slow down the rise and fall of the current —an effect which is augmented by the action of the 150ʷ inductance coil. If the battery circuit had no resistance the 10½ m.f. condenser would have no effect whatever upon the sent currents, but as there is a lamp resistance in the battery lead it considerably reduces the rate at which the current rises. The only other point which calls for comment is the arrangement of the telephone ringing circuit. Owing to the fact that the ringing current is derived from a dynamotor, which is also used to ring upon other circuits, it is necessary to prevent its direct connection to the trunk line. Many of the circuits upon which it is ringing have earth connections or possibly actual faults so that the generator becomes partially earthed—on the common battery system one side of the generator is always to earth—hence a portion of the ringing current would find its way through and produce interferences with the telegraph circuit. In order to avoid this the depression of the ringing key is caused to connect the generator to the primary winding, and thus currents are induced in the secondary (shown in Fig. 614).

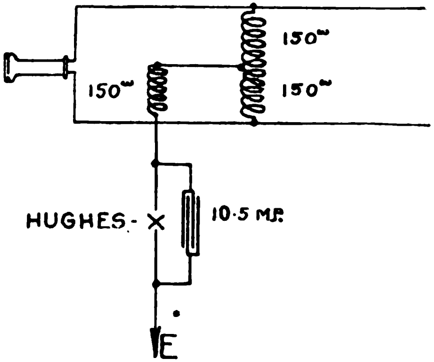

Fig. 614.—Method of superposing Hughes circuits upon the London-Paris trunk lines.

It should be stated that telegraph superposed circuits involve the abandonment of automatic signalling upon the trunk lines upon which they work and, as has been seen, involve the interpolation of tranformers at the terminal offices. In the case of offices with but one telegraph outlet the temporary abandonment of automatic signalling and the reduction of the speaking efficiency over the trunk line is far less serious than the total dislocation of the telegraphic traffic.

By either of the two methods considered any form of telegraph may be superposed upon a telephone loop. In practice, a Steljes recorder or an A. B. C. is frequently superposed upon a terminated telephone circuit, *e.g.* a telephone circuit connecting the Manchester and Liverpool offices of a company who also work a Steljes recorder over the loop.

An example of a Wheatstone duplex circuit superposed on a trunk line is illustrated in Fig. 615. A later arrangement consists in replacing the retardation coil by a 1000^{ω} resistance coil and shunting the telegraph apparatus by a 4 m.f. condenser. The two wires of the trunk line must be equal in conductor resistance, insulation resistance, capacity, and inductance to avoid interference by the telegraph signals on the telephone circuit.

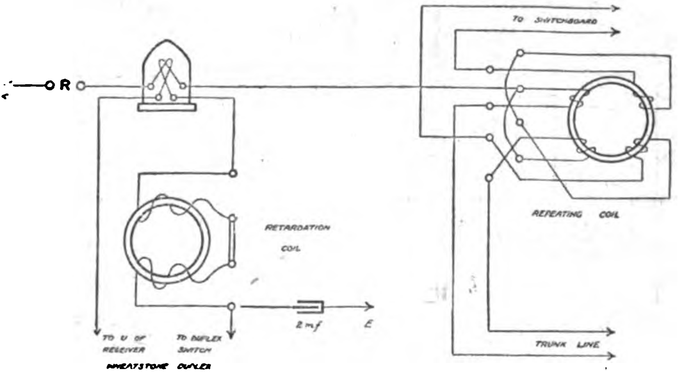

FIG. 615.—Wheatstone duplex superposed on a trunk line.

It has previously been stated that duplex circuits are superposed upon the metallic circuit quadruplexes worked through the London-Birmingham subterranean cable. This is accomplished in the manner illustrated by the skeleton diagram given in Fig. 616, from which it will be seen that the two lines are bridged by a $10{,}000^{\omega}$ resistance coil, to the centre of which an ordinary duplex set is connected. A 10 m.f. signalling condenser is placed across each of the 5000^{ω} resistances in order to hasten the rise and fall of the current in duplex circuits. The quadruplex apparatus is arranged in the usual manner save that the compensation circuit is made to resemble very closely the line circuit by connecting a series of condensers of equal capacity (·5 m.f.) and equal resistances (33^{ω}) as shown. In this way the conditions of the distributed capacity of the circuit are closely approximated—the 5 m.f. and $10{,}000^{\omega}$ being used solely to balance the signalling condenser and its resistances. Consideration will show that, since the duplex set is worked with an earth connection over both lines in parallel, the quadruplex circuit must be worked from an individual or independent battery, and for this purpose a set of small secondary cells is provided for each circuit. It will also be realized that there is no interference between the circuits, since the operation of the duplex circuit does not affect the difference of potential between the ends of the quadruplex circuit, nor does the latter, working round the loop, affect the earth-connected duplex.

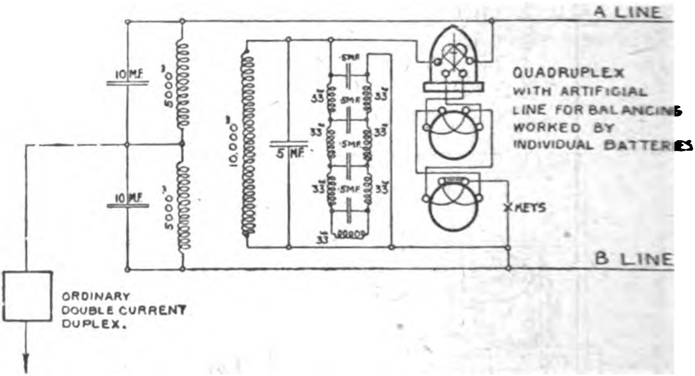
A LINE
10 MF
5000
10 MF
5000
10,000
5 MF
5MF
33
QUADRUPLEX WITH ARTIFICIAL LINE FOR BALANCING WORKED BY INDIVIDUAL BATTERIES
KEYS
B LINE
ORDINARY DOUBLE CURRENT DUPLEX.

FIG. 616.—Skeleton connection of a duplex superposed upon a metallic circuit quadruplex working through a long subterranean cable.

The full connections are shown in Fig. 617, and call for very little comment. The duplex is known as a "plus circuit." The rheostat which bridges the ends of the artificial line serves for slight adjustments of balance, but these are extremely small, since the conditions upon an underground circuit vary but little.

The various railway companies employ superposed

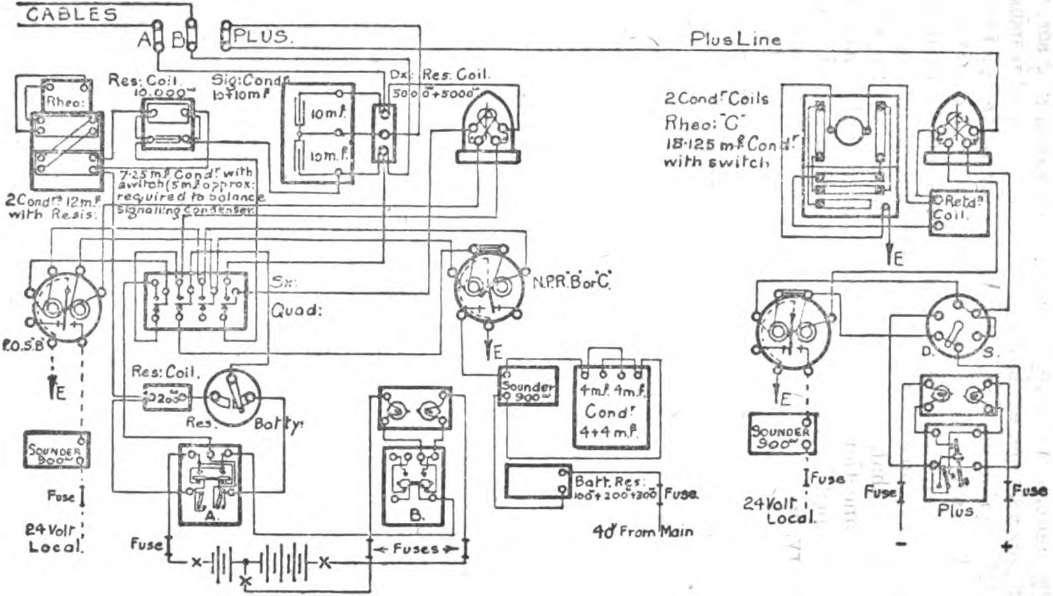

FIG 617.—Full connections of duplex superposed upon a metallic quadruplex circuit. (*B* side, local, is now arranged as shown in chap. ix).

circuits very extensively. It has been found that by modifying the arrangement of a telephone it is possible to speak over single-wire circuits of from 80 to 100 miles long, even when they are subject to an amount of inductive disturbance sufficient to prevent speech by ordinary telephones. The Phonopore Company's telephone differs from the ordinary telephone in having a receiver wound with two wires placed side by side. These windings are disconnected, and the speaking currents pass through by reason of the capacity between the two wires. The value of the capacity is extremely small, and all slowly-varying currents are practically eliminated. The speaking battery is increased to three cells. Calls are made with the aid of a vibrator consisting of an electromagnet and armature furnished with a make and break contact, as in an electric bell. The interrupted currents generate alternating currents in the secondary of the induction coil, and produce a loud note on the Collier Marr telephone receiver fixed on the receiving instrument. These details will, however, be more patent from consideration of Fig. 618.

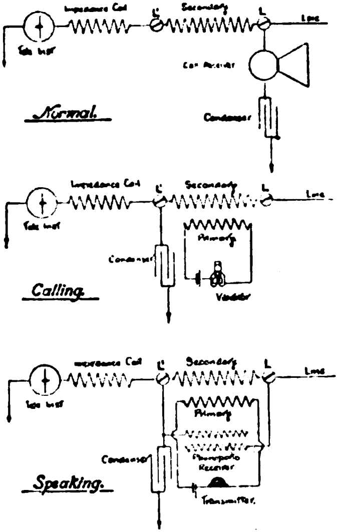

Fig. 618.—Skeleton connections of Phonopore telephones.

The single needle instruments used by the railway companies may be worked on the same single line as the telephone. An impedance coil is placed in series with the telegraph apparatus at each terminal station to slow down the rise and fall of the current and to reduce the shunting effect of the telegraph apparatus on the speaking currents to a minimum. At intermediate offices a ½ m.f. condenser is placed across each instrument to permit speaking currents to pass without encountering the inductance of the telegraph apparatus.

It may be added that inductance coils are used to separate telephone speaking currents and join together telegraph circuits, whilst condensers are employed to link together telephone circuits and to separate telegraph circuits.

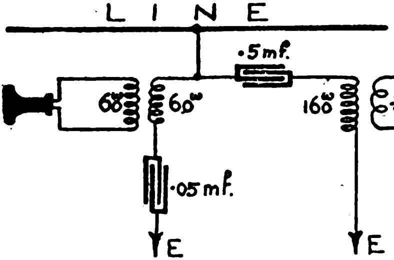

FIG. 619.—Skeleton connections of Phantophone in speaking position.

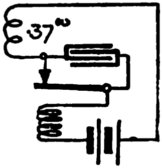

FIG. 620.—Calling device. (Key closed.)

Similar results are obtained with the phantophone in a somewhat different manner. The skeleton connections of the speaking circuit are shown in Fig. 618. The received-speech currents pass through the primary of an induction coil with equal windings and a ·05 m.f. condenser. This arrangement provides that the comparatively slow currents of the telegraph apparatus shall not seriously affect the receiver. The transmitted speech passes through the $\frac{1}{2}$ m.f. condenser direct to line. Calling is effected by applying a buzzer to the primary of the $\cdot 37^{\omega} + 160^{\omega}$ induction coil. Attention is directed to the condenser placed across the contacts of the vibrator, its function being to suppress sparking.

APPENDIX E.

CONNECTIONS FOR CREED-WORKING.

THE ordinary Wheatstone connections are used, save that a relay is substituted for the receiver. The local contacts of this relay are joined up to power and to the Creed and Wheatstone receivers as shown in Fig. 621. Sparking at the local contacts is suppressed by the 500^ω resistance coil and ·5 m.f. condensers. The shunted condenser is used to neutralize the inductance of the Creed receiver, the 500^ω resistance serving to prevent welding of the contacts (see p. 296).

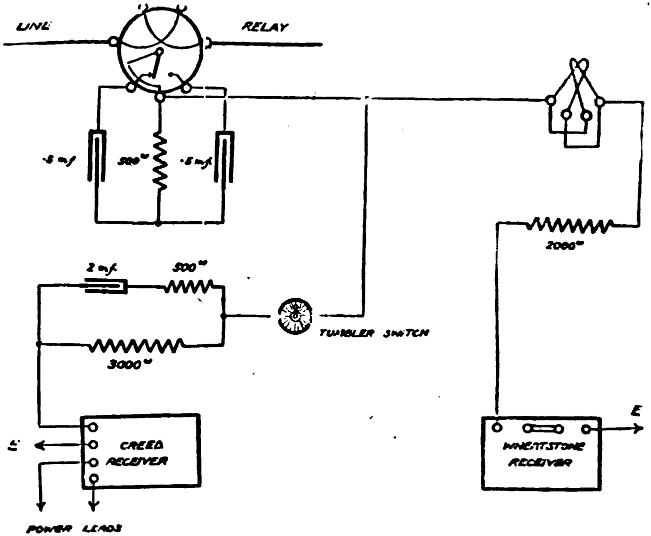

FIG. 621.—Connections for Creed working.

APPENDIX F.

THE SIEMENS HIGH-SPEED AUTOMATIC PRINTING TELEGRAPH.[*]

THIS system can be described as a single channel modified Baudot working automatically at high speed. The five-unit alphabet is adopted, but the arrangement of the characters differs both from the Baudot and Murray. Keyboard perforators are employed to prepare the slip, which is passed through a transmitter. At the receiving end the message is printed directly in Roman characters on a slip at a maximum speed of 170 words per minute. A perforated tape corresponding with the transmitting tape can also simultaneously be obtained, if required, by making certain connections to the ordinary Siemens Keyboard Perforator with the aid of a plug and cord provided for the purpose.

In comparison with the Murray Automatic and the Creed, the operation of running a received perforated tape through a printer is saved.

The outstanding points in the design of the system are:—

1. The use of the five-unit alphabet.

2. The general employment of condenser impulses to effect the various functions, contacts being broken when no current is passing.

3. The replacement of mechanical functions by electrical means. The signals are translated into printed characters with the aid of an electrical combiner and relays.

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[*] This description has been abstracted from *Electricity*, January 23, 1914; January 30, 1914; February 6, 1914; and February 13, 1914. The articles were translated from the German, and the diagrams re-drawn by H. H. Harrison.

4. The use of two groups of receiving relays, so that whilst the relays of one group are being set up to form a given combination, the other group is directing the printing operation of the last letter transmitted.

5. The generation of the synchronising effect locally from the received signals themselves.

KEYBOARD PERFORATOR.

The tape is cross perforated, and each outer edge bears a row of guide-holes like a cinematograph film. Each of the five punches is operated by an electro-magnet, and a sixth electro-magnet controls the movement of the slip after the perforation. Five contact-bars, 1 to 5, are placed beneath the key-levers, and to each key is fixed a metal comb, bearing one or more teeth according to the combination represented by the key-lever to which it is attached. Connected to the five bars are five punching electro-magnets *PM*, and a spacing-magnet *SM* (Fig. 622). Underneath the key-levers is a universal bar *UB*, which is

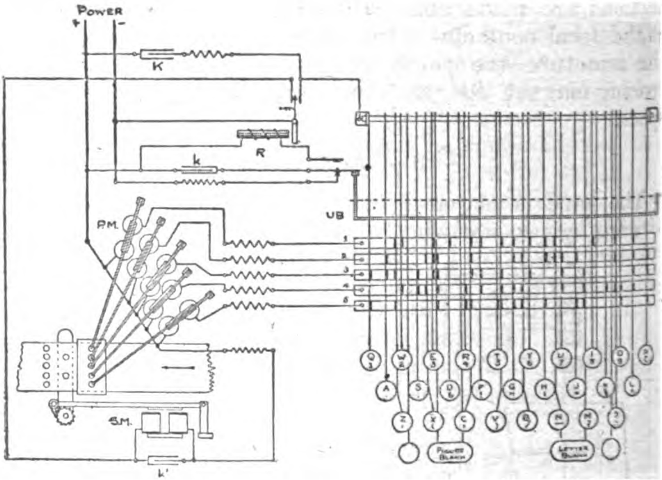

FIG. 622.—Connections of keyboard perforator.

actuated directly a key is depressed. In the normal position a condenser *k* is across the power mains through resistance, and is charged. When the universal bar is depressed it breaks the charging circuit and connects the charged condenser across the coils of the relay *R*. The armature of this relay is momentarily attracted, and closes the circuit through the punching-magnets corresponding to the particular key depressed. Thus, the duration of the closure of the magnet circuits depends only upon the time of the discharge of the condenser, and is independent of the duration of the depression of the key. It will also be observed that the only point at which connections are made and broken whilst current flows are at the local contacts of the relay *R*. On the return of the armature the power circuit is closed through the spacing-magnet *SM*, and the paper is fed forward one space.

THE TRANSMITTER.

The tape is placed in the transmitter and is driven forward by two star wheels, which engage the two rows of

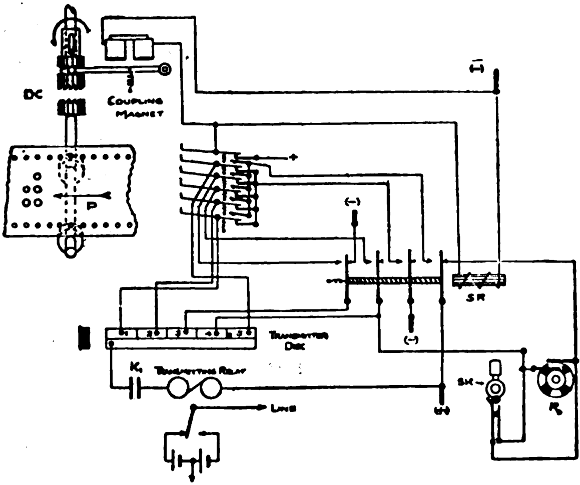

FIG. 623.—Arrangement of Siemens transmitter.

feed-holes at its edges, driven through a clutch *DC* (Fig. 623) by an electric motor.

Five of the transmitter levers, which are in reality double current keys, engage with the combinations of the five transverse punchings in the slip, whilst the sixth lever is used as explained later.

The six keys are shown to the right of the tape, and when not controlled by paper rest on their lower contact stops. The sixth and top lever of the series, when in this position, actuates the coupling magnet, and the clutch *DC* is withdrawn from the transmitter driving-shaft, thus stopping this. The circuit is also closed through the switching relay *SR*, which pulls up its four armatures on to their front contacts as shown in the diagram. Negative power is, by this means, removed from the bottom contacts on which the five signalling keys are resting.

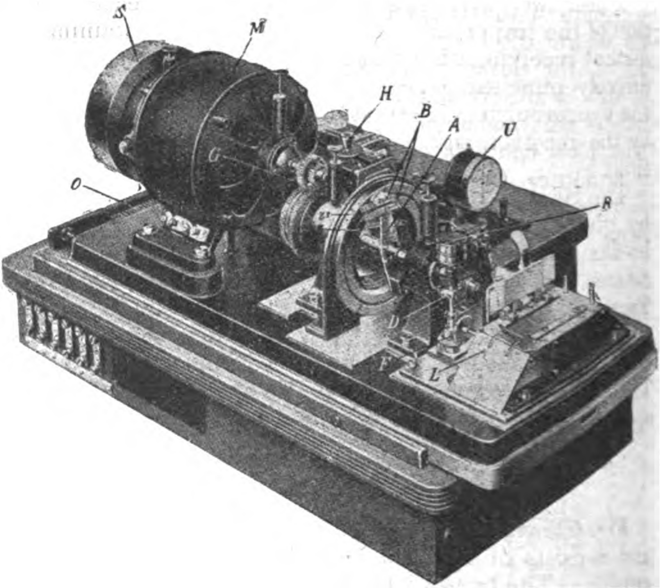

Fig. 624.—View of transmitter.

and is applied to segment No. 3 of the transmitting collector or disc, which is shown developed for the sake of clearness. The transmitting relay is actuated sending a positive current to line, the discharging current through *KI* effecting this. When the trailer reaches segment 4, the condenser has a charging path formed, and the relay now sends negative current to line.

These two currents, sent automatically at each revolution of the trailer, are for the purpose of maintaining the distant receiving distributor in synchronism. They cease directly punched paper is inserted in the transmitter, as the synchronizing effect at the far end is then generated by the received signals without any expenditure of line time.

The Switch key *SK* is for stopping the distant station by giving him a stop signal, which rings a bell. *SK* breaks the short circuit round the commutator *R*, which rotates once for every twenty-four revolutions of the trailer. From segment 3 a marking current is sent out every revolution, but the immediately following spacing-current is only sent out when the circuit is completed through *R*. Thus the series sent out is "e," "stop signal" and "letter space," with several spaces in between.

THE RECEIVER.

Fig. 625 shows the elements of the receiving apparatus, and consists of a Baudot electrical combiner, having five crowns. The type-wheel combiner brushes and receiving brush are all mounted on a common motor-driven shaft (*vide* Fig. 626), which is a general view of the complete receiver. Two groups, each of five receiving relays, are arranged so that during one revolution one group of relays is set in accordance with the combination received from the distant station, while the other group of relays is effecting the printing of the letter previously transmitted. The necessary switches, to the number of ten. are in the form of two segment commutators, and arranged on a common shaft geared to make one revolution for two revolutions of the main shaft.

The relay tongues are shown separately from their coils and placed immediately to the right of the combiner crowns. The printing of the letter is accomplished as follows:—

During a revolution the corresponding combination is received in the coils of one group of the receiving relays, and their armatures are set accordingly. Being polarized relays set neutral the tongues remain in the position they are last placed, and the signal is stored. At the end of the revolution the group of relays is switched out, and the second group put in circuit. The relay tongues are switched in circuit simultaneously with the switching out of the group of relays to which they belong, while the tongues of the group of relays now being actuated are set, but are out of the printing circuit. The combiner brushes now move from the combiner segments, and when the combination previously set is reached the

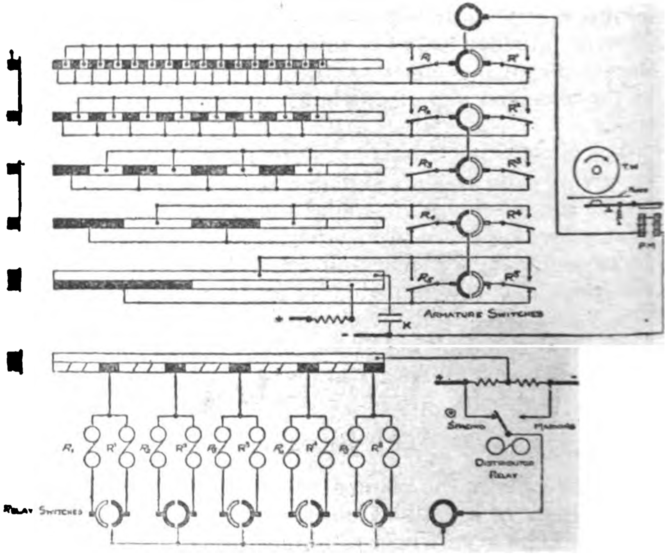

FIG. 625.—Arrangement of electrical combiner and relays.

printing-magnet is actuated. During this revolution the letter next to be printed is being set up. The printing-magnet is actuated by a condenser impulse in the following manner:—

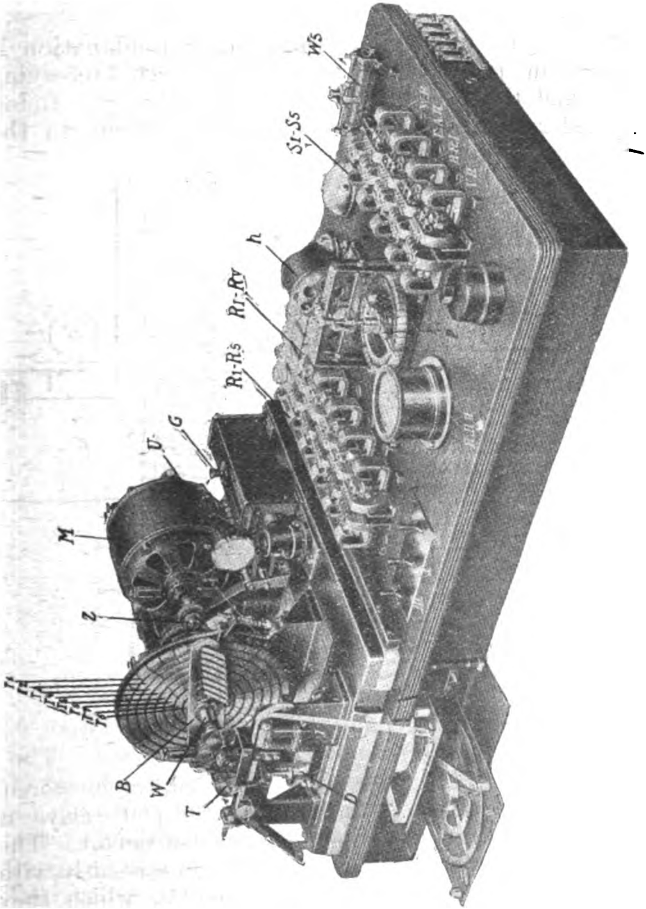

FIG. 636.—View of receiver with covers removed.

A portion of the distributor combiner is reserved for putting the condenser across the power mains through the action of the fifth brush, and as shown at the right-hand end of the fifth crown. Thus, at the commencement of each revolution, this condenser is fully charged, and is ready to discharge through the printing-magnet when the required combination is found. The printing-magnet is therefore promptly energized.

Figure 627, which for simplicity shows only one set of relay tongues, illustrates how the various functions are carried out at the receiving end. The paper feed is accomplished by a cam mounted on the main shaft. The change from letters to figures is by a lateral movement of the double type-wheel. The motion of the paper can be stopped by moving the switch-key, which withdraws the upper end of the armature of the paper-stopping magnet from the letter-spacing cam. At the same time relay *DR* is actuated, and its tongue, moving to the left, insulates the second segment of the fifth crown.

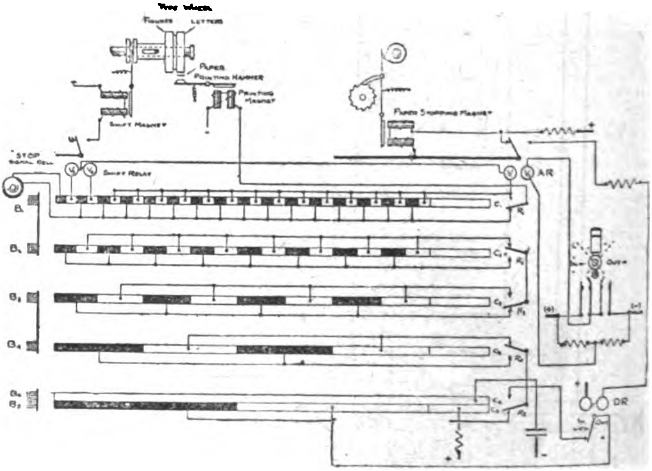

Fig. 627.—Electric combiner and printing arrangement.

The first "blank" signal is sent from the distant and will set the paper in motion again by resetting *AR* and *DR*.

SYNCHRONIZING ARRANGEMENTS

Between each of the shortened signal segments 1, 2, 3, 4 and 5 of the receiving distributor, five groups of three correcting segments are placed (Fig. 627).

Assume that the unison signal is sent from the distant transmitting station, each signal consists of the elements — — + — —. If the synchronism is perfect the brush is on the middle segment in between each signalling current, and on *V* or *Z* when a lag or lead takes place. If the brush comes on segment *V* current flows through coil *V* of the governing relay No. 1, and the armature put against contact *V*, thus putting the adjustable resistance in series with the receiver motor armature. This resistance is short-circuited if the brush lags behind on segment *Z*.

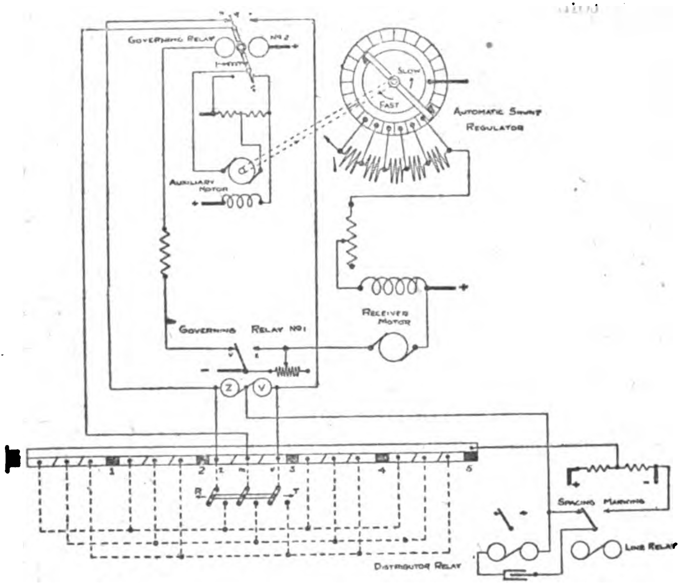

FIG. 628.—Synchronizing arrangements.

If segment *M* were isolated the acceleration or retardation would last too long, and great variations of speed would result. It is arranged, therefore, that *M* is put in connection alternately with *V* and *Z* by means of the relay tongue, *r*, and the governing relay No. 2, so that the armature resistance is switched in and out of circuit, so long as synchronism is maintained. Large variations in speed are corrected with the aid of a small auxiliary motor, which varies the resistance in the field magnet circuit of the receiver motor. Normally the armature of governing relay No. 2 oscillates between its lower contacts, and when, owing to a considerable change in speed it remains on one contact or the other, the auxiliary motor revolves until the armature of the relay again oscillates.

APPENDIX G.

SYLLABUSES OF EXAMINATIONS

I.—DEPARTMENTAL TECHNICAL EXAMINATIONS FOR PROMOTION (TELEGRAPHS).

THE subjects of examination, which comprises both a written and an oral examination, are—

I. General plan of the wiring of telegraph offices.
II. Principle and use of test-boards and testing appliances, including the Wheatstone Bridge and the Megger.
III. Crossing and looping of wires.
IV. Making up special circuits in cases of emergency.
V. Tracing and localizing of faults in apparatus and on line wires.
VI. Secondary cell working and the methods of inceasing and decreasing battery power on a circuit.
VII. Practical methods of measuring the electromotive force and internal resistance of batteries.
VIII. Joining up and adjusting telegraph apparatus, including duplex, quadruplex, and Wheatstone sets.
IX. Central Battery (simplex and duplex).
X. Hughes system, and elementary knowledge of the principles of Baudot working, at offices where these systems are in use.
XI. Repeaters at offices where these are in use.
XII. Concentrators.

XIII. Superposition; telegraph on telegraph; telegraph on telephone, etc.

XIV. Practical knowledge of trunk line working.

XV. Practical knowledge of telephone switchboards and of the apparatus used in connection therewith.

XVI. For officers in the Central Telegraph Office (except the Cable Room) as alternative to XIV and XV, Telegraph intercommunication switchboard, its construction and use.

XVII. For officers in the Central Telegraph Office (Cable Room), subjects XIV, XV, and XVI are excluded, and in subjects VIII "Hughes, Baudot, and Morse Simplex" take the place of "duplex, quadruplex, and Wheatstone."

The minimum number of marks qualifying for a position is fifty per cent. of the maximum in *both* the written *and* the oral examinations; the certificates granted will be permanently valid.

In the Central Telegraph Office, and on the telegraph side of "Divided Offices" in the provinces, no officer will be eligible for promotion to the rank of Overseer who has not passed the Departmental Technical Examination. Male Telegraphists and Sorting Clerks and Telegraphists (telegraphs) in the offices referred to may enter for the examination after 10 years' established service.

Telegraph Overseers who have not passed the examination before promotion to their present class will still be required to pass it before they can obtain further promotion. At amalgamated offices the passing of the examination before promotion is not compulsory, but in assessing qualifications for promotion importance is attached to the possession of technical certificates.

The written part of the examination is waived in the case of candidates holding a Final Grade certificate in Telegraphy, and, if required, in Telephony of the City Guilds. An old Honours Grade certificate is accepted in place of the present Final Grade.

II.—CITY AND GUILDS OF LONDON INSTITUTE.

37.—TELEGRAPHY AND TELEPHONY.

Separate Examinations will be held in (A) Telegraphy; (B) Telephony.

Candidates who hold First Class Certificates in the Ordinary Grade of Telegraphy and Telephony, issued on the results of the joint examination formerly held, may only present themselves for the Final Examination in Telegraphy or Telephony.

A.—Telegraphy.

I. Syllabus.—The examination will include questions founded on such subjects as the following:—

GRADE I.

1. *Preliminary.*—The fundamental principles of electricity and magnetism in their application to Telegraphy; units of measurement; standards of electromotive force, resistance, and capacity. Essential qualities of iron and steel for permanent and electro-magnets, methods of making permanent magnets, simple calculations relating to electro-magnets.

2. *Batteries.*—Primary and secondary, as used in telegraphy; construction and chemical action; grouping of primary batteries; calculations of the number of cells and battery power required to work circuits; the advantages of secondary batteries. The simpler methods of measuring electromotive force and resistance.

3. *Telegraph Instruments.*—The principles and construction of Wheatstone's A B C, single needle, sounder (ordinary and polarized), keys, relays, and simple switches.

Galvanometers: The principles and construction of the following types:—Astatic, differential, tangent, Thomson, and suspended coil.

Shunts and their use.

Resistance Coils: Construction of, gauge and kind of wire for, methods of winding and insulating, effect of temperature variation.

Condensers: Construction and testing of; their uses in the simpler telegraph systems.

Inspection and testing of telegraph instruments.

4. *Telegraph Lines.*—Aërial, underground, and submarine; construction of, and relative advantages of each class.

Testing instruments employed and methods of using them in the simpler tests; apparatus employed by linemen.

Faults in: their nature; general principles of localization.

5. *Telegraph Systems.*—The simpler systems of manual telegraphy, including single and double current duplex, common battery systems and universal working; also simple methods of cable telegraphy.

6. *Miscellaneous.*—Earth currents, nature of, and methods of preventing disturbance therefrom.

Methods of protecting lines and apparatus from (*a*) Lightning, (*b*) Power circuit currents.

Suitable illustrative diagrams should be systematically introduced into answers.

FINAL EXAMINATIONS.

Candidates for the Final Examination must hold a Certificate in Grade I.

In addition to more difficult questions on the subjects of Grade I, questions will be set in the subjects enumerated below:—

1. *Preliminary.*—Units, absolute and practical; relations of electro-static and electro-magnetic units.

2. *Secondary Cells.*—Chemistry of, care of, method of charging, capacity and efficiency of, testing, method of equalizing output and distribution of current, switching and protective arrangements.

3. *Construction.*—Testing of materials employed.

Aërial lines; factor of safety; stresses on poles; static and kinetic stresses on wires; law connecting sag and stress; regulation of wires.

Underground lines; modern practice.

Submarine lines; manufacture, laying, and repairing. Internal wiring of large telegraph offices.

4. *Telegraph Instruments.* — Wheatstone apparatus, Hughes, Baudot, the siphon recorder, the undulator and cable relays; general principles of construction.

5. *Telegraph Systems.*—Wheatstone, quadruplex, type-printing telegraphs; concentration, inter-communication and common battery systems; methods of working long submarine cables; superimposed circuits; simultaneous telegraphy and telephony.

6. *Repeaters.*—Principles of, simplex and duplex; forked and divided quadruplex.

7. *Telegraphic Transmission.*—The effects of capacity and inductance in circuits; methods of reducing, compensating for, and eliminating the same; laws governing the speed of working on long aërial, underground, and submarine lines.

8. *Testing.*—Apparatus: Wheatstone bridge; tangent, ballistic and reflecting galvanometers; ammeters; voltmeters: theory, construction and methods of use. Localization of earths, contacts, and disconnections on line wires; capacity, resistance, inductance, and insulation measurement; measurement of resistance and E.M.F. of batteries; Post Office Morning Test system.

9. *Wireless* (*or Radio-*) *Telegraphy.*—Theory of; principal systems in use; construction of aërial gear; transmitting and receiving apparatus; wave measuring devices.

10. *Miscellaneous.*—Variable period of a current; Helmholtz's equations; Kirchhoff's and Maxwell's laws; electro-magnet coils, simple formulæ for.

Suitable illustrative diagrams should be systematically introduced into answers.

APPENDIX H.

EXAMPLES ON THE CALCULATION OF THE CAPACITY OF CIRCUITS.

THE average value of the capacity K in microfarads of an aërial wire d mils in diameter, h mils above the ground, and l miles in length, may be obtained from Kempe's formula:—

$$K = \frac{\cdot 0616\, l}{\log \frac{4h}{d}}$$

The number ·0616 is an experimentally determined constant and refers to wires erected in this country.

Example. What is the average capacity per mile of a 70 lb. bronze wire (diameter 66 mils) suspended 30 feet above the ground?

$$K = \frac{\cdot 0616 \times 1}{\log \frac{4 \times 360{,}000}{66}} = \frac{\cdot 0616}{4.34} = \cdot 0142 \text{ m.f.}$$

The capacity K in electrostatic units of two co-axial cylinders l cms. long separated by a material having a specific capacity k, where D is the outside diameter of the inner, and d the inside diameter of the outer, cylinder is given by the formula:—

$$K = \frac{l\, k}{2 \log_e \frac{D}{d}} \; *$$

---

* The proof of this formula, involving a simple application of calculus, is given in the more advanced of the elementary treatises on electricity; see J. J. Thomson's "Elements of the Mathematical Theory of Electricity and Magnetism," page 93.

This formula may be applied to the case of a cable core, and taking, for example, a mile of 7½ G.P. wire ($D = 174$ mils, $d = 50$ mils, and $k = 4{\cdot}2$), and putting the whole of the dimensions in centimetres, the capacity

$$= \frac{1760 \times 36 \times 2{\cdot}54 \times 4{\cdot}2}{2 \log_e \dfrac{{\cdot}174 \times 2{\cdot}54}{{\cdot}05 \times 2{\cdot}54}} \text{ electro-static units.}$$

Dividing by 9×10^5 to convert the result in static units to microfarads, and also multiplying the denominator by 2·3026 to convert the natural into a common logarithm, the capacity is

$$= \frac{1760 \times 36 \times 2{\cdot}54 \times 4{\cdot}2}{2 \times 2{\cdot}3026 \times \log_{10} \dfrac{{\cdot}174}{{\cdot}05} \times 9 \times 10^5} = {\cdot}301 \text{ m.f.}$$

As a further illustration of this formula it will be interesting to apply it to the case of a screened conductor cable, and so determine the approximate specific capacity of the air and paper dielectric (all paper with exception of the small helical air space)—

$$k = \frac{K 2\log_e \dfrac{D}{d}}{l} \text{ where } K \text{ is in static units.}$$

Substituting the figures for a 230 mil core having a 50 mil conductor, expressing the capacity of one mile of cable (·095 m.f.) in static units, and converting to common logarithms:—

$$k = \frac{{\cdot}095 \times 9 \times 10^5 \times 2 \times 2{\cdot}3026 \times \log \dfrac{{\cdot}230 \times 2{\cdot}54}{{\cdot}050 \times 2{\cdot}54}}{1760 \times 36 \times 2{\cdot}54}$$

$= 1{\cdot}62$ as compared with the 4·2 of G.P.

A few simple problems based upon the formula for the capacity of two co-axial cylinders are given by way of conclusion—

Example I. Find the relative capacities of two G.P. cables of equal length, A having a conductor 100 mils in diameter and a core of 200 mils, whilst B has a 200 mil conductor and a 500 mil core (log 2 = ·30103)—

$$A : B : : \frac{l k}{2 \log_e \dfrac{200}{100}} : \frac{l k}{2 \log_e \dfrac{500}{200}}$$

$$\text{i.e. } A : B : : \log \frac{10}{4} : \log 2$$

$$: : \log 10 - \log 4 : ·30103$$

$$\text{But } \log 10 = 1 \text{ and } \log 4 = 2 \log 2$$

$$\therefore A : B : : ·39794 : ·30103$$

Example II. Find the relative capacities of one mile of G.P. covered cable, A 80 mil conductor and 100 mil core and B 120 mil conductor and 180 mil core, given log 2 = · 30103 and log 3 = ·47712—

$$A : B : : \log \frac{180}{120} : \log \frac{100}{80}$$

$$\text{or} \quad A : B : : \log \frac{3}{2} : \log \frac{10}{8}$$

$$\text{or} \quad A : B : : \log 3 - \log 2 : 1 - 3 \log 2$$

$$A : B : : ·17609 : ·09691$$

Example III. Compare the working speeds of two G.P. cables of equal length A, having a 60 mil conductor with a total diameter of 100 mils, and B having a 100 mil conductor insulated with G.P. 85 mils thick (log 2 = ·30103 and log 3 = ·47712).

Notes. The working speeds may be assumed to be inversely proportional to the KRs, and as the lengths are equal the resistances are inversely proportional to the squares of the respective conductor diameters. The total diameter of the core B = 270 mils—

Let R_A, R_B, K_A, K_B, S_A, S_B, represent the resistances, capacities, and speeds of the cables.

$$R_A : R_B : : 100^2 : 60^2$$

$$K_A : K_B : : \log \frac{270}{100} : \log \frac{100}{60}$$

or $K_A : K_B :: 3 \log 3 - 1 : 1 - (\log 3 + \log 2)$

i.e. $K_A : K_B :: \cdot 43136 : \cdot 22185$

$S_A : S_P :: K_B \times R_B : K_A \times R_A$

$S_A : S_P :: \cdot 22185 \times 100^2 : \cdot 43136 \times 60^2$

i.e. $S_A : S_P :: 2218 \cdot 5 : 1552 \cdot 9$

Example IV. What must be the thickness of the G.P. insulation in order that a 100 mil conductor shall have the same capacity per unit length as a 120 mil conductor having a core diameter of 200 mils?

$$\log \frac{200}{120} = \log \frac{x}{100}$$

$$\therefore \frac{200}{120} = \frac{x}{100}$$

$$i.e. \ x = 167 \text{ mils}$$

The thickness of the G.P. covering is therefore—

$$\frac{167 - 100}{2} = 33\tfrac{1}{2} \text{ mils.}$$

APPENDIX I.

USEFUL NUMBERS.

CONVERSION OF LENGTHS, WEIGHTS, ETC.

1 inch	=	2·54 centimetres	1 cm.	=	·3937 in.
1 yard	=	91·44 centimetres	1 metre	=	39·37 ins.
1 mil.	=	·0254 millimetres	1 mm.	=	39·37 mils.
1 sq. in.	=	6·4516 sq. cms.	1 sq. cm.	=	·1550 sq. in.
1 cubic in.	=	16·387 c. cms.	1 cubic in.	=	·06102 c. cm.
1 grain	=	·064799 gramme	1 gm.	=	15·432 grains
1 ounce	=	28·3495 grammes	1 gm.	=	·035274 oz.
1 pound (7000 grs.)	=	453·59 gms.	1 gm.	=	·0022046 lb.

1 kilogramme or 1000 grammes = 2⅕ lbs. approx.

The gramme is the mass of a cubic centimetre (*i.e.* 1 millilitre) of water at a temperature of 4° C.

1 gallon of water occupies ·1604 cubic foot and weighs 10 lbs. at 62° F.

1 cubic foot of ice weighs 57·5 lbs.

CENTIGRADE AND FAHRENHEIT TEMPERATURES.

To convert temperatures in the Fahrenheit scale to the corresponding Centigrade temperature deduct 32° and take $\frac{5}{9}$ of the result.

To convert Centigrade to Fahrenheit multiply by $\frac{9}{5}$ and add 32°.

CIRCLES AND SPHERES.

Let r = radius and
d = diameter.

Circumference of a circle $= 2\pi r = \pi d$

Area " " $= \pi r^2 = \frac{\pi}{4} d^2 = \cdot 7854\, d^2$

Surface of a sphere $= 4\pi r^2 = \pi d^2$

Volume " " $= \frac{4}{3}\pi r^3 = \frac{\pi}{6} d^3$

CONSTANTS.

$\pi = 3{\cdot}1415926536$ or $3{\cdot}1416$ approx. or roughly $\frac{22}{7}$

$\pi^2 = 9{\cdot}86965$; $\sqrt{\pi} = 1{\cdot}77245$; $\frac{1}{\pi} = {\cdot}31831$

Angle for which the arc is equal to the radius, 1 radian, $= 57{\cdot}2958^\circ = 3437{\cdot}75' = 206265''$.

Base of natural logarithms 2·7183.

To convert common to natural logarithms multiply by 2·3026 and by ·4343 to convert natural to common logarithms.

Weight of 1 lb. in London = 445,000 dynes.

1 foot-pound $= 1{\cdot}3562 \times 10^7$ ergs.

1 horsepower = 33,000 foot lbs. per minute = 746 watts.

Value of the acceleration of gravity = 32·182 feet or 981·17 cms. per second, *i.e.* the force of gravity = 981·17 dynes.

HEAT PRODUCED BY A CURRENT.

1 calorie = heat required to raise 1 gramme of water at 4° C to 5° C.

Joule's equivalent $J = 42 \times 10^6$ ergs per calorie.

The heat H generated in a circuit of R ohms resistance by a current of C amperes in t seconds.

$$H = {\cdot}24\, C^2 R t = {\cdot}24\, E C t = {\cdot}24\, \frac{E^2}{R}\, t$$

APPENDIX J.

STANDARD WIRE GAUGE.

No. S. W. G.	Diameter.		Area in square inches.	No. S. W. G.	Diameter.		Area in square inches.
	Mils. (·001 inch.)	Milli- metres.			Mils. (·001 inch.)	Milli- metres.	
7/0	500·	12·70	·1963	23	24·	·610	·000452
6/0	464·	11·78	·1691	24	22·	·559	·000380
5/0	432·	10·97	·1466	25	20·	·508	·000314
4/0	400·	10·16	·1257	26	18·	·457	·000254
3/0	372·	9·45	·1087	27	16·4	·417	·000211
2/0	348·	8·84	·0951	28	14·8	·376	·000172
0	324·	8·23	·0824	29	13·6	·345	·000145
1	300·	7·62	·0707	30	12·4	·315	·000121
2	276·	7·01	·0598	31	11·6	·295	·000106
3	252·	6·40	·0499	32	10·8	·274	·0000916
4	232·	5·89	·0423	33	10·0	·254	·0000785
5	212·	5·38	·0353	34	9·2	·234	·0000665
6	192·	4·88	·0290	35	8·4	·213	·0000554
7	176·	4·47	·0243	36	7·6	·193	0000454
8	160·	4·06	·0201	37	6·8	·173	·0000363
9	144·	3·66	·0163	38	6·0	·152	·0000283
10	128·	3·25	·0129	39	5·2	·132	·0000212
11	116·	2·95	·0106	40	4·8	·122	·0000181
12	104·	2·64	·0085	41	4·4	·112	·0000152
13	92·	2·34	·00665	42	4·0	·102	·0000126
14	80·	2·03	·00503	43	3·6	·0914	·0000102
15	72·	1·83	·00407	44	3·2	·0813	·00000804
16	64·	1·63	·00322	45	2·8	·0711	·00000616
17	56·	1·42	·00246	46	2·4	·0610	·00000452
18	48·	1·22	·00181	47	2·0	·0508	·00000314
19	40·	1·016	·00126	48	1·6	·0406	·00000201
20	36·	·914	·00102	49	1·2	·0305	·00000113
21	32·	·813	·000804	50	1·0	·0254	·000000785
22	28·	·711	·000616				

ADDENDUM

THE AMPLIFYING VALVE[*]

THIS type of relay is probably destined in the future to play an important part in ordinary telegraphy and it has already been developed to such an extent for telephone trunk circuits that the problem of long underground telephone cables is solved. It will in future rarely be necessary to provide conductors exceeding 20 lbs. per mile in gauge, and it is evident that ultimately telegraph and telephone circuits will be contained in the same cable without mutual interference. This will render the line plant far more flexible and the need for separate telegraph and telephone cables will disappear. Of the use of the device in wireless telegraphy and wireless telephony, it may be said that the results now obtainable in every day practice were undreamed of in the days prior to its advent. Of its multifarious uses during the war it is yet too early to speak, but it may be said in general terms that it was used most extensively by both victors and vanquished.

The thermionic relay (which is the appropriate designation of the amplifying valve) differs from an ordinary electromagnetic relay in that (i) there are no moving parts and it is therefore free from mechanical inertia, (ii) it has no inductance, and (iii) it supplies an amplified current which approximates very closely to the incoming current, whereas an ordinary relay merely makes a contact which introduces into the local circuit a fixed value of current quite unrelated to the value of the incoming current subject to the qualification that the latter is of sufficient value to work the relay. It is therefore capable of repeating and amplifying telephone currents from one circuit to another without appreciable distortion of the wave form. It is moreover possible to introduce several repeaters into a very long circuit, such as that between San Francisco and New York. In the reception of wireless signals thermionic valves are connected in cascade to obtain amplification on amplification. Here it may be well to explain that the thermionic relay is known by many names, the excuse for some of which is not unconnected with patent rights. The term "valve" is in general use in wireless telegraphy since the Fleming 2-electrode valve was first used as a detector for wireless reception, and was so arranged as to rectify the received alternations by reason of the fact that it permits a current to pass in one direction only. The terms thermionic valve, ionic valve, amplifying valve or thermionic relay are used indiscriminately. The term gas discharge relay and vacuum tube amplifier are more general terms which include also somewhat similar but, so far undeveloped, types.

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[*] The description is abstracted from the following papers read before the Institution of P.O. Electrical Engineers :—No. 76 "Gas discharge telephone relays and their application to commercial circuits"—"Technical developments of telephonic repeaters since 1917," by C. Robinson and R. M. Chamney, and No. 75 "Telephonic repeaters" by A. B. Hart.

See also "The evolution of the thermionic valve" by R. L. Smith-Rose, *Journal of the I.E.E.*, Vol. 56, No. 273, April, 1918. *Guide to the study of the Ionic Valve*, by W. D. Owen (Pitman).

Gas discharge relays consist of some form of vacuum tube, through which a direct current discharge is maintained. The discharge current can be made extremely sensitive to the influence of weak voice currents, a small alternating current producing proportional, but greatly magnified, variations in the discharge. In order to explain how this is accomplished it is necessary to give a brief outline of the theory of conduction of electricity.

The three possible methods of conduction have been termed the "bird seed" method, the "bullet" method and the "fire bucket" method respectively.* The bird seed method applies to liquids, and is exemplified in electrolysis; the bird carries the seed with it and only drops it when it reaches the electrode. The bullet method is the method in rarefied gases. The space from the kathode to the anode represents the length between the breech and muzzle of the gun, and the rest of the path is the trajectory of the bullet. In the particular case of amplifying valves the anode is so disposed and so designed that the path of the electron ends with and is absorbed by the anode. The fire bucket method must be the method of conduction in solids where the atoms are not capable of locomotion and can only pass electrons on from hand to hand oscillating a little in one direction to receive them, and in another direction to deliver them up and so getting thrown gradually into a state of vibration which is called heat.

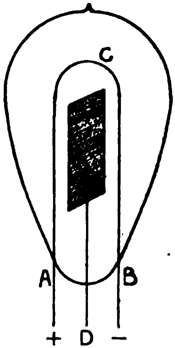

FIG. 620.—Edison Effect.

If a charged body is thoroughly insulated and surrounded by dry air or other gas it remains charged for a long time. A slight leakage, however, generally occurs, which is not due to the support, but takes place through the surrounding gas. It is, therefore, necessary to assume the presence of "carriers" of electricity in the gas. Investigations as to the nature of the "carriers" were facilitated by the discovery that the conductivity of gases is immensely increased by the presence of hot bodies, flames, or electric arcs. The *Edison effect* was obtained by placing a platinum plate between the legs of the horse shoe filament of an incandescent lamp (when it was found that, the filament being heated by direct current), a current

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* *Journal of the I.E.E.*, Vol. XXXII, No. 159, Electrons, by Sir O. J. Lodge.

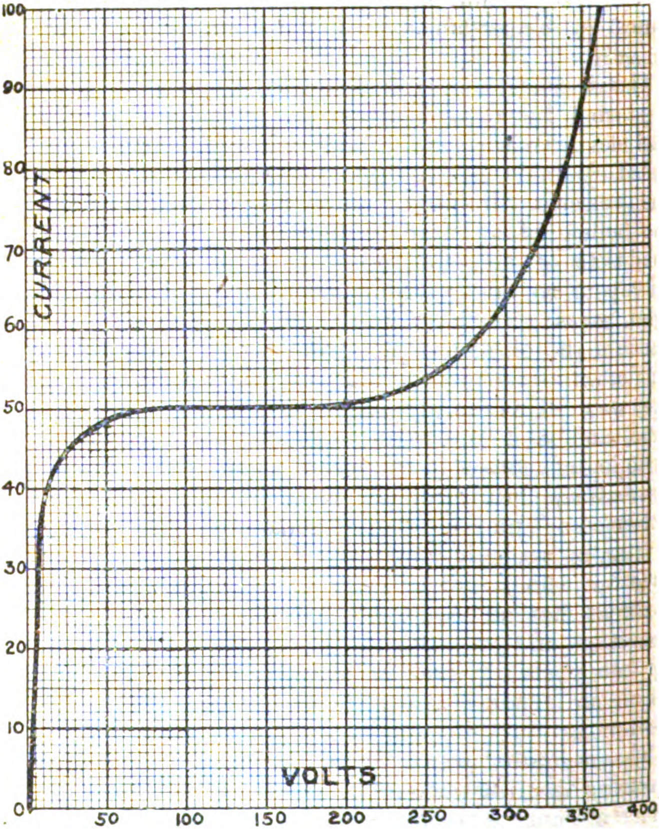

FIG. 630.—Curve showing relation between the voltage impressed on the Electrode and the resulting current through the gas.

was observable on a galvanometer connected between the plate and the positive terminal. The space between the filament and the cold electrode possesses unidirectional conductivity. Current will usually pass from the cold to the hot electrode, but not in the reverse direction. This current is not, however, in general proportion to the impressed voltage, but varies in accordance with the curve shown in Fig. 630.

The discharge between a hot and a cold electrode is started by the liberation of negatively charged particles from the hot kathode. These particles are called electrons, and possess a definite mass, charge, and velocity. Indeed, the process is analogous to the boiling of a liquid; for, just as under certain conditions of temperature and pressure a liquid gives off vapour, so, under other conditions, the incandescent solid gives off electrons. In an extremely high vacuum the electrons pass from the kathode to the anode without encountering any particles of gas on the way. This constitutes a current through the tube, and it is interesting to note that the actual direction of motion of the electrons is opposite to the conventional "direction of current." Such a discharge is termed a "pure electron discharge."

If an appreciable quantity of gas is present in the tube and the impressed voltage is high enough, the electrons moving at a high velocity collide with the molecules of gas causing the molecules to split up into positively and negatively charged particles which are termed "ions." This action is termed ionization.

The negative ion is identical with the original electrons liberated from the kathode, and has the power of ionizing the molecules of the gas by collision as it passes towards the anode. The positive ion is larger than the negative ion and moves towards the kathode with a lower velocity, and is, therefore, less active in ionizing the gas. The ionizing action due to the positive and negative ions would bring about an indefinite multiplication of free ions were it not that recombination of positive and negative ions also takes place. This results in a steady state being reached, depending upon the conditions of pressure, etc., in the tube. Ionization is accompanied by a characteristic luminous glow.

The various stages of conduction may be explained by reference to Fig. 630, which shows the relation between the voltage impressed on the electrodes and the current through the gas in the discharge tube. As the voltage is increased from zero to about 30 volts, the current rises due to the arrival of an increasing number of electrons at the anode. The velocity of the electrons is not, however, sufficient to produce ionization, and a stage is reached when an increase in voltage, from 70 to 200, produces no appreciable rise in current. The point at which the current ceases to rise with a rise in voltage, is called the saturation point, and it is reached when the voltage is sufficient to drive the electrons from the kathode to the anode without imparting to them sufficient velocity to produce ionization. As the voltage rises above 200 the electrons move with a higher velocity and ionization commences. This results in a rapid rise in current which continues until an arc is formed.

It may be of interest to give some idea of the magnitude of the quantities dealt with :—

Mass of electron : $3{\cdot}4 \times 10^{-17}$ grammes (10^{-3} of hydrogen atom).

Ratio Charge/Mass : 10^{-7} electro-static unit.

Velocity : 10,000 to 90,000 miles per second.

Mass of positive electron : $3{\cdot}4 \times 10^{-14}$ (about equal to hydrogen atom).

Ratio Charge/Mass : $3{\cdot}3 \times 10^{2}$

The current is influenced to a very great extent by the presence of minute quantities of impurities which it is not always practicable to eliminate in commercial lamps. It has, therefore, been found preferable to use hard or very high vacuum lamps, and thus to obtain a pure electron discharge. More stable conditions result, and there is not the wide difference in performance observable between soft or low vacuum lamps of similar manufacture.

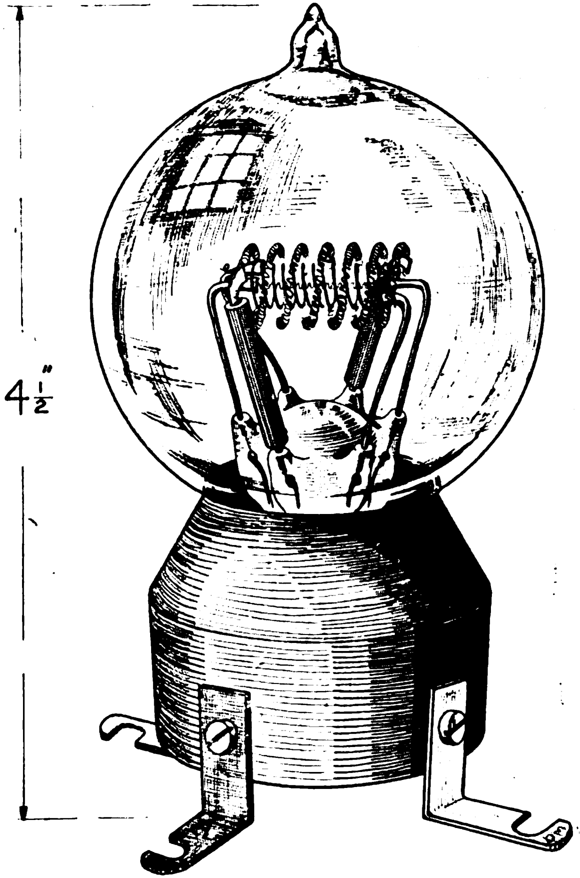

FIG. 631.—Thermionic Valve.

The broad general principle* of the thermionic relay is that incandescent bodies at a temperature of 1500°C or so give off electrons, but three conditions are essential: (1) the body must be supplied with negative electricity, (2) the body must be in a fairly good vacuum, and (3) there must be a positively charged body near to create the electric force necessary to drive off the electrons. This is achieved in the two electrode valve by the use of an incandescent filament in an exhausted bulb (which J. A. Fleming used as a rectifier, hence the term valve). The modification introduced by De Forrest consisted in placing a grid between the filament and the plate. If this grid is electrified negatively, it repels the electrons and reduces the plate current. If it is charged positively, it increases the plate current. The variations of the plate current follow exactly the variations of the grid potential*

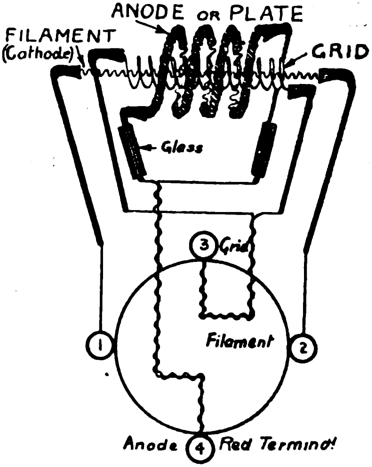

FIG. 632.—Arrangement of Valve.

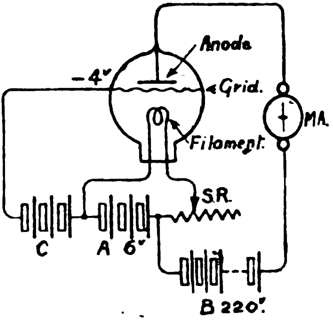

FIG. 633.—Thermionic Valve Circuit.

The P.O. "amplifying valve," Figs. 631 and 632, as

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*Dr. J. A. Fleming in the discussion on "Telephonic repeaters," by A. B. Hart, 22nd Nov., 1918, *Journal of the I.P.O. E.E.*, No. 75.

it is officially designated, consists of a cylindrical spiral of tungsten wire placed in the centre of the grid, which is a similar spiral of alloy wire with a radius of about one-eighth of an inch, and the anode forms a second spiral of wire concentric with the grid at a radius of about a quarter of an inch.

The filament, Fig. 633, is maintained at a constant heat by a 6^v battery *A*, and the normal current, (rather less than one ampere), is adjustable by means of the slide resistance SR. The anode is maintained at a constant high potential, generally about 220 volts, by the battery *B* which is in series with the *A* and *B* batteries. The *C* battery consists of 3 small dry cells.

With the connections as indicated in Fig. 633 and an anode battery of fixed value it will be found (as the filament is gradually brought up to incandescence by cutting out resistance in *SR*) that at a certain critical value, the milliamperemeter begins to indicate a current in the anode-filament or plate circuit, this current will increase as the heating current is increased until a maximum value is reached, after which any increase in the heating current causes no change in the plate circuit. The normal value of this current is about 5 milliamperes with present valves and 150^v plate battery, so that the impedance of the plate circuit is of the order of $20{,}000^\omega$.

Imagine, now, that the grid is connected to a source of potential, slowly changing from a few volts negative to a few volts positive with respect to the grid. The milliamperemeter in the plate circuit will indicate a current changing from 2 to 0 or from 2 to 4 m.a., and the changes in this current exactly coincide with the changes in the potential of the grid. When the grid is at its lowest negative potential the plate current will be 0 and will gradually rise until it reaches a maximum when the grid is at its highest positive potential. The capacity of the grid is exceedingly minute, and therefore the energy ($\frac{1}{2}$ KV) required to change its potential is very small. The grid potential is consequently varied through a comparatively wide range by the very small energy waves received from the line circuit; or the arrangement may be regarded as a relay tongue having no weight or inertia, moved by minute energy pulsations and by its movement releasing the energy of the high voltage discharge battery. The power received at the end of a circuit equivalent to 20 miles of standard cable is about 40 micro-watts.

In application to a telephone circuit the line circuit is connected to the primary of a transformer (input), the secondary of which is joined between the negative pole of the *C* battery and the grid, whilst the milliamperemeter is replaced by the primary of the output transformer, whose secondary is connected to the outgoing line. This provides only for uni-directional amplification, and in order to meet practical conditions, conditions somewhat resembling those of a duplex telegraph repeater are arranged.

The incoming energy may be magnified a thousandfold by a valve, and as has been stated, several valves may be placed in cascade—indeed, as many as 19 valves (giving a magnification of about a million times) were so used by the Navy to pick up certain buzzer signals passing between German ships.

Magnification of Atlantic cable signals has already been effected with the thermionic relay. Thus far the device has not been used in ordinary inland telegraphy, but there are many possible directions in which it may be required in the future as, for example, in reducing telegraphic line currents, and thus to minimise inductive disturbances on adjacent circuits. The question arises as to working telegraph circuits by currents of telephonic strength and frequency. Then, too, there is the possibility of a multiplex system on the Mercadier principle, and by using various frequencies and tuned receiving apparatus.

WEAK CURRENT TELEGRAPHY.

It seems probable that most subterranean telegraph circuits will be worked as metallic circuits, and that the power used will be greatly decreased so as to prevent interference with telephone loops in the same cable. Experiment has shown that Wheatstone working with a current of from 5 to 10 m.a. and a voltage not exceeding 40 is possible when the speed does not exceed 200 words per minute. It has been found that this speed was practicable on a metallic circuit 190 miles long consisting of 40 lb. conductors, and this without appreciable interference with the adjacent telephone circuits. The cable used was not loaded, but it was balanced. Balancing consists in measuring carefully the capacities of the various conductors in each section, and then arranging the jointing of the pairs together in such a manner as to produce accurate balance on the jointed length.

On a 200 lb. loop circuit 210 miles long a duplex speed of 200 words per minute was obtained, with a voltage of 13½ by using the standard *G* vibrating relay.

A series of extended trials were made recently on a balanced cable containing loaded and unloaded pairs by A. H. Roberts, W. J. Hilyer, and F. Lock,* and their results are summarized as follows—

(1) Over a loop circuit 186 miles in length a speed of 150 words per minute duplex can be obtained with 40 volts on the differential system and 60 volts on the bridge system.

(2) The induction on loaded telephone pairs is less from differential than from bridge Wheatstone working.

(3) If the steady line current is raised without altering the surge current, the induction on the

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* "Combined Telephone and Telegraph Cables: Important Trials by A. H. Roberts, W. J. Hilyer, and F. Lock," *P.O.E.E. Journal*, Vol. xiii, p. 29.

telephone loop is unaffected. (The steady current may be varied without altering the battery surge current on a long line by adjusting the resistance at the receiving end.)

(4) The increase in the battery surge current caused by increasing the main voltage or speed of running increases the induction.

(5) Induction on loaded telephone pairs is increased when the number of Wheatstones working on loops in the cable is increased, but the resultant noise is not proportional to the number of Wheatstones.

(6) Ordinary loop circuits working at 40 volts give about the same induction on a loaded telephone loop as single wire earth return circuits working at 20 volts, when the wire twisted with the line wire is earthed at each end so as to screen the line wire. If, however, the single wire circuit is worked at a higher voltage, it gives greater induction than the loop.

(7) If "bunching" be allowed for the Wheatstone circuits in a cable, it is better to form each "leg" from a pair than from two "*a*" or two "*b*" wires of two pairs (the two "legs" must be in the same 4-wire core).

(8) If superposed Wheatstone working be permitted, the Wheatstone should be superposed on two telephone pairs and worked as a loop. In the trials made, the induction in the side circuit on which the Wheatstone was superposed was marked.

(9) When a thermionic telephone relay was inserted in a telephone cable line, the disturbance caused by induction from Wheatstones was not increased beyond the induction noted without the relay in the listening circuit.

(10) No degrading effect on speech was noted on the loaded circuits when fourteen 40 volt Wheatstone transmitters were running on unloaded loops in the same cable.

WORKING SPEED OF CABLE CIRCUITS.*

From time to time endeavour has been made to combine the factors which limit the speed of subterranean and submarine cables into formulæ which would enable the speed of any cable to be calculated theoretically. The empirical formulæ assumed a constant for each type of dielectric, but the omission from the calculation of many factors which are known to exist led to wrong results, and in most cases the speeds actually obtainable were much lower than those which should have been possible if the theoretical basis were correct.

At present, the only safe method of calculating the speed of a circuit is by comparison with the known rate of working on a circuit of similar construction but of different length.

It may be added that Wheatstone apparatus is now tested for a maximum speed of 300 words per minute only—the commercial branch having found that a speed of about 250 meets all their needs.

OVERHEAD TELEGRAPHS,

CIRCUIT EFFICIENCY AND FACTORS OF SAFETY.†

In this country the atmospheric conditions are such as to make the loss of current due to low insulation the predominating factor which limits the length of overhead telegraph wires. For example, the distance between Repeater offices is usually about 200 miles for fast speed apparatus, in which the receiving instrument is a P.O. standard relay *B* or its equivalent.

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* The Author is indebted to Mr. A. H. Roberts, M.B.E., for the information contained in this section.

† I am indebted to Mr. J. L. Taylor for the account of his researches contained in this section of the Addendum. The reader should also refer to Mr. J. L. Taylor's articles in the *P.O.E.E. Journal*, Vol. x, pp. 78, 218, Vol. xi, pp. 19, 74 and 207.

The more important systems of working in use on aerial wires include the following—

(1) Key double current Morse.
(2) Fast speed telegraphs.
(3) Quadruplex with 40 and 120 volts.
(4) C.B. Telegraphs, special Head Office sets, 80 volts.
(5) C.B. Telegraphs ordinary Head Office sets, 80 volts.
(6) C.B. Telegraphs, Duplex with relay at out office.
(7) C.B. Telegraphs, Duplex with polarized sounder at out office.
(8) Quadruplex with 24 and 80 volts.
(9) C.B. Telegraphs with primary batteries.

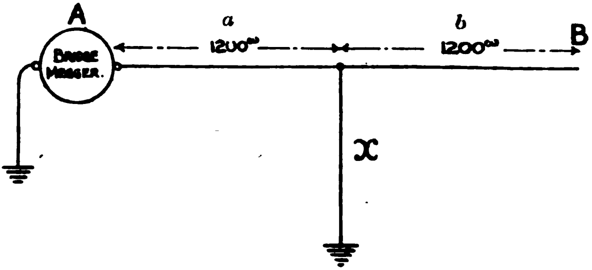

FIG. 634.—Test 1 with B Disconnected R_1.
Test 2 with B Earthed R_e.

In the cases of (1), (2), (3), and (8) the reception will depend upon two factors, viz., (*a*) received current, and (*b*) speed; in cases (6) and (7) the system is complex, consisting as it does of a combination of double current working outwards and single current decrement working inwards; in cases (4), (5), and (9) the limiting conditions depend upon the voltage drop at the Head Office apparatus set, and this is affected to a great extent by the leakage conditions on the line.

For the cases (4), (5), and (9) it is usual to apply calculations on the basis of steady voltage values and for the purpose of comparison it is convenient to arrive at the limiting distances for the other types of apparatus sets on the same basis. As $E = C \times R$, it will be clear that loss of current is proportional to voltage drop, and the same principle may, therefore, be applied to all classes of circuit. In order to compensate for the attenuation of signals due to high speed working, the minimum received currents in the latter case are given a higher value.

In arriving at approximations to the limiting distances for different types of apparatus sets on this basis, it is necessary to assume that the insulation loss is uniformly distributed, and that the leakage may be represented as a resultant earth fault at the centre of the line resistance (see Chapter XXI.).

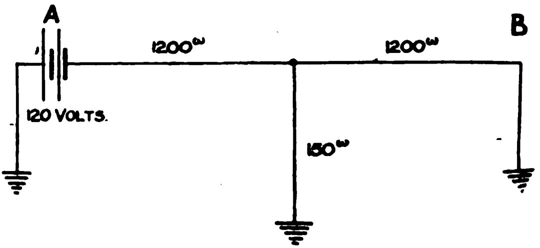

Fig. 635.—24,000ω Circuit with 150ω Leak in Centre.

If the circuit is L miles long and has a conductor resistance per mile of r_a ohms, then the calculated conductor resistance (R_a) will be $L \times r_a$.

Suppose $L = 400$ miles and $r_a = 6^{\omega}$ per mile, then $L \times r_a = 400 \times 6 = 2400^{\omega} = R_a$.

If two fixed resistances of 1200^{ω} are connected as shown in Fig. 634, x being a variable resistance, and two tests be made for each value of x, viz., Test 1 with B disconnected (call the reading obtained R_1) and Test 2 with the end B connected to earth (call the reading obtained R_c) the results shown in Table 1 will be obtained.

TABLE 1.

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(j)
Value of x .	Inf.	9600	7200	4800	2400	1200	600	300	150
R_1 .	Inf.	10800	8400	6000	3600	2400	1800	1500	1350
R_c .	2400	2266·6	2228·5	2160	2000	1800	1600	1440	1333·3
Value of x in terms of R_a	Inf.	$4R_a$	$3R_a$	$2R_a$	R_a	$\frac{1}{2}R_a$	$\frac{1}{4}R_a$	$\frac{1}{8}R_a$	$\frac{1}{16}R_a$

From column (j) it will be seen that when x is made 150^{ω}, the value of R_1 is 1350^{ω} and R_c is $1333{\cdot}3^{\omega}$. The values of R_1 and R_c tend to approach each other as the value of x is decreased. Fig. 635 shows the case represented under column (j), but a battery of 120^{V} is applied in this instance.

The sent current

$$C_s = \frac{120}{1200 + \dfrac{1200 \times 150}{1200 + 150}} = \frac{120}{1333{\cdot}3} = 90 \text{ m.a.}$$

and the received current

$$C_r = \frac{150}{1350} \times 90 = 10 \text{ m.a.}$$

Now, when x = infinity, the sent current C_s equals the received current C_r = the perfect current $C_p = \dfrac{120}{2400} = 50$ m.a. So that the percentage of perfect current lost is $\dfrac{40}{50} = \dfrac{x}{100}$ or $x = \dfrac{4000}{50} = 80\%$.

TABLE 2.

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(j)
Value of x .	Inf.	$4R_a$	$3R_a$	$2R_a$	R_a	$\frac{1}{2}R_a$	$\frac{1}{4}R_a$	$\frac{1}{8}R_a$	$\frac{1}{16}R_a$
Percentage loss of perfect current . .	0	5·88	7·69	11·5	20	$33\frac{1}{3}$	50	$66\frac{2}{3}$	80
Ratio R_1/R_c .	Inf.	4·76	3·76	2·77	1·8	1·33	1·125	1·04	1·01

Table 2 shows the percentage loss for each of the cases shown in Table 1 together with the respective ratio of R_1 to R_c in each case.

From Table 2 it will be clear that the received current increases as the value of the ratio R_1/R_c increases, and in the application of this principle to overhead telegraph wires it will be evident that a close approximation to the percentage loss of perfect current can be obtained by dividing the insulation resistance reading by the conductor resistance reading, and thus obtaining the value of the ratio R_1/R_c (see Fig. 636).

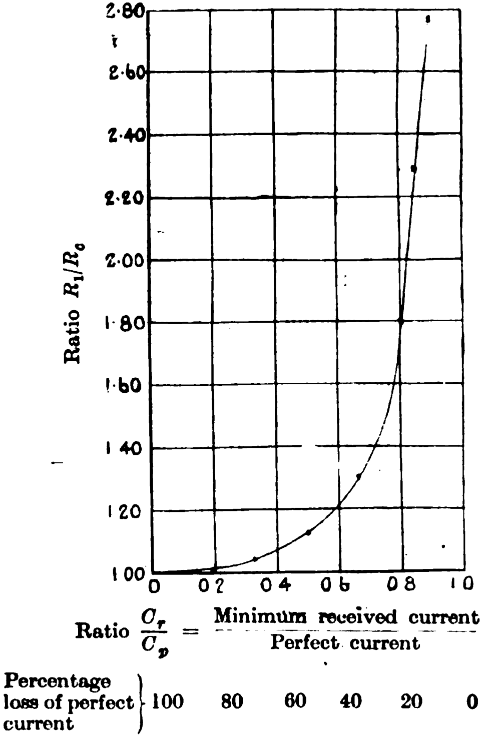

FIG. 636.—Curve Connecting R_1/R_c and C_r/C_p.

These results may be applied to working conditions, for Kennelly, in his work on "The Application of Hyperbolic Functions to Electrical Engineering Problems," states that for an equivalent T circuit (such as has been assumed, Fig. 634) the values of the elements in the equivalent circuit of a line may be written down in terms of the observed resistances R_1 (Insulation) and R_c (Conductivity) by using the following correcting factors; *i.e.*,

$$\text{The equivalent value of } a = b = R_1\left(1 - \sqrt{1 - \frac{R_c}{R_1}}\right)$$

$$\text{and the equivalent value of } x = R_1\sqrt{1 - \frac{R_c}{R_1}}$$

By way of illustration, assume that the observed readings obtained are as in (g), Table 1, in which $R_1 = 1800$ and $R_c = 1600$, the ratio R_1/R_c being 1·125.

$$\text{Value of } a = b = R_1\left(1 - \sqrt{1 - \frac{R_c}{R_1}}\right)$$

$$\frac{R_c}{R_1} = \frac{1600}{1800} = \frac{1}{1{\cdot}125} = 0{\cdot}\dot{8} = \frac{8}{9}$$

$$\text{and} \quad \sqrt{1 - \frac{8}{9}} = \sqrt{\frac{9-8}{9}} = \sqrt{\frac{1}{9}} = \frac{1}{3}$$

$$\text{so that} \quad a = b = R_1\left(1 - \frac{1}{3}\right). = R_1\left(\frac{3-1}{3}\right) = \frac{2}{3}R_1$$

$$= \frac{2}{3} \times 1800 = 1200$$

$$\text{also value of} \quad x = R_1\sqrt{1 - \frac{R_c}{R_a}} = \frac{1}{3}R_1$$

and $\frac{1}{3}R_1 = 600$. That is to say, $a = b = \frac{2}{3}R_a$ and $x = \frac{1}{3}R_a$ (see Table 1 (g).)

All the values of the figures obtained by means of the Leakage Conductance Theory method can be verified in this way, and, in addition, the resultant leakage path resistance can be determined for cases in which the mileage is not exactly at the limiting distance, and from the equivalent T circuit thus obtained the voltage and current calculations are placed on the simple basis of the "Perfect Current" conditions represented by a wire of known resistance per mile and of a given length.

For given insulation resistance conditions the value of x will decrease with the length of the line, so every additional mile also adds about 30 additional points of leakage, each point of leakage representing a telegraph pole.

To arrive at approximations to the limiting mileages on the basis of the steady value received current minima is therefore a comparatively simple matter, as it is only necessary to determine the approximate percentage loss of perfect current that can be allowed for each type of apparatus set. The problem is simplified by the fact that in this country voltage from a universal battery system is limited to a maximum of 120 volts. Table 3 shows approximations to the mileage limitations arrived at on this basis.

TABLE 3.

Type of circuit and voltage.	Line minimum ratio R_1/R_c.	Percentage loss of perfect current.	Length of circuit in miles.
Key D.C. Morse with relay (120 volts) . . .	1·01	80%	$\frac{1000}{\sqrt{r_a}}$
Fast speed Telegraphs (120 volts)	1·04	66⅔%	$\frac{700}{\sqrt{r_a}}$
Quadruplex with 40 and 120 volts	1·125	50%	$\frac{490}{\sqrt{r_a}}$
Quadruplex with 24 and 80 volts	1·8	20%	$\frac{223}{\sqrt{r_a}}$

In Table 3 r_a is the conductor resistance per mile. If $r_a = 9^{\omega}$ per mile, then the maximum overhead mileage for a Wheatstone duplex fast speed telegraph circuit will be approximately $\frac{700}{\sqrt{9}} = \frac{700}{3} = 267$ miles. For this type of line wire a circuit of 534 miles length would therefore require a repeater set at the half-way distance.

The values shown in Table 3 assume duplex working and the use for reception of low terminal resistance apparatus of the type equivalent to the P.O. standard relay *B*.

The fast speed formula $700/\sqrt{r_a}$ comprises different *types* of apparatus sets, such as "Wheatstone duplex with receiver direct on line," "Wheatstone duplex with receiver on locals of standard relay *B*," "Wheatstone duplex with receiver on locals of standard relay *G*," "Baudot," and other multiplex systems in which a standard relay is utilized for the reception of line signals. Although classified under one formula, there are slight differences in respect of mileage limitations

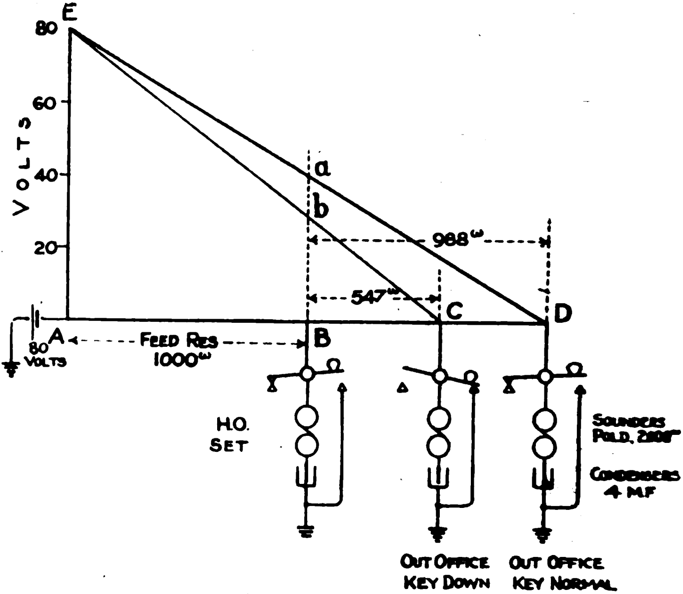

FIG. 637.—C.B. Telegraph Circuit.

for which allowance would require to be made in practice.

In "Central Battery duplex with relay at the out office," the limiting condition is reached when the insulation resistance is 1·8 times the conductor resistance reading. When the ratio R_1/R_c falls below this value (1·8) the effective voltage is insufficient to actuate the armature of the non-polarized relay at the Head Office set and the local circuit is therefore permanently closed—maximum length L (miles) $= 223/\sqrt{r_a}$.

When a polarized sounder $100^{\omega} + 100^{\omega}$ is in use at the out office on a C.B. duplex circuit, the limiting condition is that of the sounder when used as a C.B.S. Head office set, viz., L (miles) $= 141/\sqrt{r_a}$. This is due to the difference in the volume of sound obtained at the out office under the two conditions of out office set key up and key down, when the voltage drop on the line reaches the point indicated by the mileage limit given.

The limiting mileage of C.B.S. circuits worked from secondary cells is indicated in Fig. 637, which shows graphically a C.B.S. circuit comprising 75 miles of 100 lbs. copper wire $L \times r_a = 75 \times 8{\cdot}78 = 659^{\omega}$.

The insulation conditions shown are such that

$$R_1 = 1{\cdot}5\, R_a = 1{\cdot}5 \times 659 = 988^{\omega}$$

and
$$R_c = {\cdot}83\, R_a = {\cdot}83 \times 659 = 547^{\omega}$$

and
$$\frac{R_1}{R_c} = \frac{938}{547} = 1{\cdot}8.$$

A secondary battery of 80 volts is applied at A (Fig. 637) and with a line insulation resistance of 988^{ω} the fall of potential of the E.M.F. along a resistance path of 1988^{ω} is represented by the line E_aD on Fig. 637.

The Head Office set is connected at the end of the feed resistance shown at B (Fig. 637), and the potential at B when the out office key is normal will therefore be that at (a), i.e.—

$$= \frac{988}{1988} \times 80 = 39{\cdot}75 \text{ volts.}$$

When the out office key is depressed, the conductor resistance will be 547 and the fall of potential will be along the line E_bC. That is to say, the potential at B

will drop from a to b. The potential at b will be equal to $\frac{547}{1547} \times 80 = 28{\cdot}28$ volts.

The voltage drop at B will therefore be—

$$(a - b) = (39{\cdot}75 - 28{\cdot}28) = 11{\cdot}47 \text{ volts.}$$

As the combination of a 2000^{ω} polarized sounder and a 4 m.f. condenser will respond to a voltage drop of about 11 volts, the apparatus at B will respond to signals under the control of the key at the out office.

The conditions in which $R_1 = 1{\cdot}8\,R_c$ represent the limiting line conditions.

Now, when $R_1 = 1{\cdot}8\,R_c = 1{\cdot}5\,R_a$, the value of x (Fig. 637) is equal to R_a. (See Table 2.)

In the case under consideration $R_a = 659$ and the length L of the circuit is 75 miles also, $75 \times 659 = 49425$. It can be shown that for the C.B.S. R_1/R_c ratios the product of the length of the circuit L (miles) and the resultant leakage path resistance x is practically a constant represented by 50,000 at the maximum distance given by the formulæ, and similarly, that the constant is practically 60,000 in the case of the ratios R_1/R_c, equal to 1·01, 1·04, and 1·125. If this value be called r_o, then it may be said that $\frac{r_o}{L} = 659 = R_a = x =$ the equivalent resultant leakage path resistance for the given value of the ratio R_1/R_c.

On this hypothesis, it was shown that

$$R_1 = \frac{R_a}{2} + x = \frac{R_a}{2} + \frac{r_o}{L}$$

but $\quad R_1 \text{ also} = 1{\cdot}5\,R_a$

$$\therefore \quad \left(\frac{R_a}{2} + \frac{r_o}{L}\right) = 1{\cdot}5\,R_a$$

whence $\quad LR_a = r_o$

but $$R_a = L \times r_a$$

$$\therefore \quad L \times L \times r_a = r_o$$

$$L^2 = \frac{r_o}{r_a}$$

Calling $$r_o = 50000$$

$$L^2 = \frac{50000}{r_a} \qquad L = \frac{\sqrt{50000}}{\sqrt{r_a}}$$

$$L = 223/\sqrt{r_a} \text{ miles.}$$

When a standard relay B (with coils in series) plus a 1000^ω resistance coil in series replaces the 2000^ω polarized sounder D at the Head Office set the voltage drop $(a - b)$ (Fig. 637) required to actuate the combination may be regarded as $5\frac{1}{2}$ volts.

Calling $(a) = V_1$ and $(b) = V_2$

$$V_1 - V_2 = 5\tfrac{1}{2} \text{ and } V_1 = \frac{R_1}{f + R_1} \times V$$

$$V_2 = \frac{R_c}{f + R_c} \times V$$

where V = impressed voltage = 80

and f = feed resistance

$$\therefore \quad V_1 - V_2 = \frac{R_1}{f + R_1} \times V - \frac{R_c}{f + R_c} \times V$$

$$= V\left(\frac{R}{f + R_1} - \frac{R_c}{f + R_c}\right)$$

and $$\frac{V_1 - V_2}{V} = \frac{R_1}{f + R_1} - \frac{R_c}{f + R_c} = \frac{5 \cdot 5}{80} = \text{say } \frac{1}{15}$$

No material error will arise if it be assumed that the insulation resistance R_1 may fall to the value of the feed resistance f, so that it may be considered $f = R_1$

$$\frac{1}{15} = \frac{R_1}{2R_1} - \frac{Rc}{R_1 + R_c} = \frac{R_1^2 + R_1R_c - 2R_1R_c}{2R_1(R_1 + R_c)}$$

$$\frac{1}{15} = \frac{R_1^2 - R_1R_c}{2R_1^2 + 2R_1\,R_c}$$

whence $$\frac{R_1}{R_c} = \frac{17}{13} = 1{\cdot}3$$

That is to say, to obtain the required voltage drop at the Head Office set under all conditions, the worst line conditions should be such that the insulation resistance R_1 shall not be less than 1·3 times the conductor resistance R_c.

From Table 2 it will be seen that when

$$x = \tfrac{1}{2}R_a \text{ then } R_1/R_c = 1{\cdot}33$$

with $$x = \tfrac{1}{2}R_a \text{ then } R_1 = R_a$$

and $$R_1 = R_a = \left(\frac{R_a}{2} + \frac{r_o}{L}\right)$$

or $$R_a = \frac{LR_a + 2r_o}{2L}$$

$$2LR_a = LR_a + 2r_o$$

$$LR_a = 2r_o$$

$$L \times L \times r_a = 2r_o$$

$$L^2 = \frac{r_o}{r_a} \times 2$$

with $$r_o = 50000 \quad L^2 = \frac{100000}{r_a}$$

or $$L = \frac{\sqrt{100000}}{\sqrt{r_a}}$$

$$L = 316/\sqrt{r_a}$$

Central Battery Simplex with Primary Batteries.— When a central primary battery is used, the secondary battery mileages are not approached in consequence of two factors: (1) the use of a 2000^{ω} feed resistance, (2) the voltage drop in the primary battery due to internal resistance.

With 80 volts the following mileage limitations are usually applied, viz.—

For two circuits worked from a central primary battery, L (miles) $= 158/\sqrt{r_a}$.

For six circuits L (miles) $= 100/\sqrt{r_a}$.

THE VIBROPLEX.

This device is in extensive use in America to prevent telegraphists cramp by relieving the operator of the work of forming the separate dots. It consists of a lever which is moved to the right to send dots, and to the left for dashes. It carries a weighted spring which, when the movement is to the right, is thrown into vibration, thus making and breaking a contact at a predetermined rate depending upon the position of the timing weight. The dashes are formed by the operator by movements of the lever to the left. This device necessitates the formation of the signals sent out on a local sounder, so that the sender may only hold the key over to the right whilst the required number of dots are formed by the automatic vibration of the weighted spring. The sender does not feel any movement of the lever whilst it is held to the dot side. What it amounts to is that the operation of the key is from side to side, and that instead of the 2, 3, 4, or 5 movements necessary to send the dots required, the lever is merely maintained on the right side for a varying period of time until the required number of dots have gone out.

It is contended that the device permits faster sending with less fatigue to the operator, and that the strain on the receiving operator may be reduced by taking the message on a typewriter. In this way it is claimed that higher output is secured, and the possibility of telegraphist's cramp is reduced. Whether these claims can, any or all of them, be substantiated in practice remains to be determined, since the experiments in progress are not yet conclusive. It is, however, true that when the device was tried some twenty years ago it was, at that time, condemned by most practical telegraphists in this country.

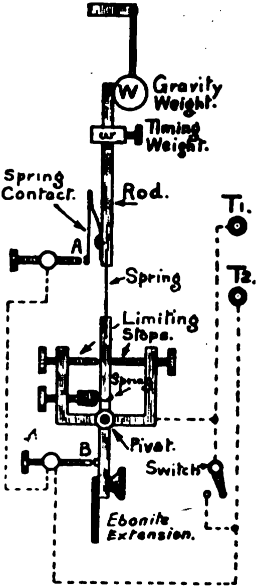

FIG. 638.—The Vibroplex.

Telegraphists cramp is neither very rare nor is it extensive, and there is some reason to think that in many cases where it does occur the prime cause lies in bad teaching and the consequent development of unnatural jerky methods of sending. The replacement by properly adjusted double current keys for single current type keys on all busy circuits should tend to reduce the risk of cramp, even where the art of rythmical sending has either never been acquired or has been impaired due to some obscure physical condition of the operator.

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